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How to Predict the Spread and Intensity of Forest and Range Fires

Richard C. Rothermel

THE AUTHOR

RICHARD C. ROTHERMEL is a research engineer stationed at the Northern Forest Fire Laboratory in Missoula, Mont. Rothermel received his B.S. degree in aeronautical engineering at the University of Washington in 1953. He served in the U.S. Air Force as a special weapons aircraft development officer from 1953 to 1955. Upon his discharge he was employed at Douglas Aircraft Co. as a designer and trouble shooter in the armament group. From 1957 to 1961 Rothermel was employed by the General Electric Co. in the aircraft nuclear propulsion department at the National Reactor Testing Station in Idaho. In 1961 Rothermel joined the Northern Forest Fire Laboratory, where he has been engaged in research on the mechanisms of fire spread. He received his master's degree in mechanical engineering at the University of Colorado, Fort Collins, in 1971. He was project leader of the Fire Fundamentals Research Work Unit from 1966 until 1979 and is currently project leader of the Fire Behavior Research Work Unit at the fire laboratory.

RESEARCH SUMMARY

This manual documents the procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. It contains instructions for obtaining fuel and weather data, calculating fire behavior, and interpreting the results for application to actual fire problems. Potential uses include fire prediction, fire planning, dispatching, prescribed fires, and monitoring managed fires.

Included are sections that deal with fuel model selection, fuel moisture, wind, slope, calculations with nomograms, TI-59 calculations, point source, line fire, interpretations of outputs, and growth predictions.

PREFACE

When Hal Anderson and I came to the Northern Forest Fire Laboratory in 1961, it was not yet a year old and there was a feeling that surely this lab was going to contribute. Just what would be accomplished was not entirely clear, but things were going to happen. There was also a sense of being overwhelmed, not only by all the unknowns of wildfire behavior, but also by how to use this brand new facility. There were at least two schools of thought in regard to the wind tunnels: (1) bring in box-car loads of fuel from all over the country for burning in the wind tunnels, and (2) weld the doors shut until a logical plan for use of the facilities was developed.

We did not weld the doors and we did not ship in fuel by the box-car load, but we did work hard at understanding fire spread and adapting concepts of modeling and systems to the problems of forest fire prediction. During the first 10 years a fire behavior model was produced. It took 10 more years to learn how to obtain the inputs and interpret the outputs for use by the "man on the ground," which culminated in the writing of this manual. Specialized versions of the prediction methods have been available for some time in automated forms, such as the National Fire Danger Rating System and the slash hazard appraisal system.

No manual of this size, covering the diverse material needed to analyze fire conditions, can be a solo production. It could not have been done without the man who crusaded for the laboratory facilities and who was the first lab chief, Jack Barrows. His paper (Barrows 1951) showed us "industry types" how fire could be examined, but more importantly his continual optimism and confidence gave us the inspiration so necessary for a project that was to take 20 years to pull together.

Many outstanding people have worked on this problem, as shown by the publications cited. I must single out a few for special acknowledgment, mostly members of Research Work Unit 2103 at one time or another.

No one could ask for a steadier and more reliable partner in a 20-year endeavor than Hal Anderson, who started work at the lab with me in 1961. He and Jim Brown, who came a couple of years later, are recognized leaders in fuel research. Bill Frandsen joined the project in 1967 and the scientific staff at that time consisted of just Bill and me. Bill established the basis for the fire spread model with his analysis of the conservation of energy on a spreading fire. Charlie Philpot came to the lab while he was earning his Ph.D. under Dr. Shafizadeh at the University of Montana and gave great assistance in the area of fuel chemistry. We were exceedingly fortunate to have excellent technicians during this time, including Merlin Brown, who ran the wind tunnels, Bob Schuette, who constructed innumerable fuel beds, Walt Wallace, who handled the chemical analysis, and Bobbie Hartford, an invaluable assistant in the field and in the lab.

In the late 60's the idea of fire management generated a whole new list of problems for research that were spelled out in a paper by Chandler and Roberts (1973). Fortunately, about this time we hired Frank Albini, an outstanding analyst who straightened out our modeling and let the genie out of the bottle with publication of his book of nomographs in 1976. That same year the first fire behavior officers' (FBO's) course was organized at Marana, Ariz. Ernie Anderson, director of the training center at Marana, insisted that we put together a fire prediction system that a man could use on the line or in a plans tent and teach it in 2 weeks. I am not sure how to describe the early sessions, but students who have taken the course hail each other as graduates or survivors of the class of '76 or '77, etc. The course was successful; however, some of the early material was so weak that the students should have chased all of us instructors off the base. Instead, their support encouraged us to improve the course and eventually to write this manual. Students who successfully complete the course can now receive 2 hours of credit at the University of Arizona.

Ernie Anderson also predicted that we would have computers on the fireline. Three years later a project initiated by John Deeming, Jack Cohen, and Bob Burgan, and finished by Bob Burgan, resulted in just that—a microchip for the TI-59 calculator. During the transition from nomograms to calculator, Pat Andrews from our project has superseded me as an instructor at Marana; her interest in applying research results has resulted in outstanding contributions to fire management.

Instructors from many places have participated since the first class. Steve Sackett took on the difficult task of bringing realism to fuel moisture assessment and the tough job of providing fuel beds for burning each year. The meteorologists, Clyde O'Dell, Frank Gift, and Dave Goens, have made that difficult subject understandable.

The instruction for FBO's at Marana has now been largely taken over by experienced field personnel who were former students. Some have made outstanding contributions to fire technology; these include Dave Aldrich, Rod Norum, Jim Elms, and John Chapman from the class of '76; George Rinehart, John Shepherd, Gordie Schmidt, and Bill Williams, class of '77; Larry Keown, Ed Mathews, Ron Prichard, Jan Van Wagtendonk, and Mike Templeton, class of '78; and Randy Doman and Steve Holscher from the class of '79.

Of course the hardest workers on this text, with its endless tables, figures, exhibits, exercises, and examples, as well as revisions, have been Lucille Davis and Gladys Look, our clerks, and Carolyn Chase, a mathematician who has organized all of the material for publication.

This is not a complete list of contributors; others are mentioned in the text, and considerable support came from the directors at Marana, Ernie Anderson, Jerry Mauk, and Dick Henry, and course leaders Joe Duft, Larry Mahaffey, Bonnie Turner, Hank LaSala, and Don Willis. The staff of the Intermountain Research Station must be recognized for its accomplishments in technology transfer and for allowing so much time and effort to be devoted to an area normally shunned by research. I appreciate their support.

To everyone I express a heartfelt thank you.

CONTENTS

How to Predict the Spread and Intensity of Forest and Range Fires

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INTRODUCTION

Can wildland fire behavior really be predicted? That depends on how accurate you expect the answer to be. The minute-by-minute movement of a fire will probably never be predictable—certainly not from weather conditions forecasted many hours before the fire. Nevertheless, practice and experienced judgment in assessing the fire environment, coupled with a systematic method of calculating fire behavior, yields surprisingly good results. This manual documents the procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. The procedures are complete and can be applied by individuals working in the field. It does not address the problems of large fuel burnout or duff consumption and duration of burning. The methods pertain to the fine fuels that carry the fire and produce the flames at the fire front. Although there are several tables and condensed procedures that can be extracted for a field reference, most of the procedures must be learned and practiced diligently to produce proficiency and useful results.

The material is extensive for good reason. Fire behavior, fuels, and meteorology are extremely complicated subjects that can bear limited condensation before losing sensitivity. Consequently, no apologies are given for the length. If you have not seen these methods before, some perspective is needed to avoid overenthusiasm or undue skepticism. It should be clear to anyone who has observed wildland fires that there is considerable variability in the fuels, the windspeed, and other influences that rule out the ability to make absolute predictions. It should also be clear that a few easily identified variables can cause drastic differences in the way fires burn and spread. Fuel compactness is a good example. Sparse dead grass and tightly packed pine needles have completely different burning characteristics even though individual pieces of each are physically similar. Similarly, fuel moisture, wind, and slope can all produce dramatic differences in spread rate and intensity. The effect of changes in these major variables upon fire behavior is accounted for by the fire model within the system. The difficulty in use arises in the estimation of the most appropriate inputs for situations that appear very diverse. Prediction accuracy is dependent upon the skill and knowledge of the user and the degree of uniformity or lack of uniformity of the fuels and environmental conditions.

This manual is no substitute for experience, but rather by coupling experience with a systematic prediction method, the professionalism needed for implementing new concepts in fire management is emerging. Large fires where fire behavior can be carefully studied are considerably fewer than earlier in this century. Ironically, this comes at a time when fire management policy brings greater demands for quantitative assessment of fires. This manual is intended to help fill this need.

The manual is a compilation of material developed for the National Wildfire Coordinating Group's S-590 Fire Behavior Officer Course[1] and from a 3-day course in predicting fire behavior using the TI-59 calculator equipped with a preprogramed chip. New research material has been added in an evolutionary process since the methods were first developed and tried in the field in 1976.

Until now, access to these methods was available only through the 2-week S-590 course. This manual cannot replace that training, but can serve as a text providing the material to those who cannot attend the course, and as a reference for those who do. It may also be used to supplement the material in the revised S-390 fire behavior course.[2]

As the citations will show, many persons have been involved in the development of the material. Much of the material has not previously been published, however, making it difficult to cite. It is important to document the work and give proper credit before the origin is lost.

The material has been tried and refined considerably since first taught in the FBO class in 1976. In fact, the material has been greatly strengthened by former students who have helped refine the techniques and test them operationally.

I have eliminated extraneous material that is useful only to fire behavior officers, such as the instructions for preparing briefings and forecasts. However, examples of how the prediction methods are integrated into the fire planning strategy and material that a fire behavior officer might prepare for them are given in appendix G. I have not attempted to condense it for quick reference in the field, but rather depend on the user to apply only those sections needed for a particular situation. The style is narrative and cites examples, rather than a step-by-step procedure. The manual must be thoroughly learned so that the appropriate section can be recalled immediately when needed. Approximately 200 fire behavior officers have been trained and tested in these procedures. Responses regarding its usefulness have been very encouraging. As you become proficient in the use of the material, I believe you will achieve a new level of professionalism in fire management.

The literature citations provide a good record of the background material used to develop this manual. There are a few publications that should be cited as being especially helpful for application of this material:

Weather—Schroeder and Buck (1970)
Fuels—Anderson (1982)
Calculations—Albini (1976) and Burgan (1979)
Spot fire distance—Chase (1981)
Interpretation—Andrews and Rothermel (1982)
Verification—Rothermel and Rinehart (1983)

[1]This 2-week course is taught at the National Advanced Resource Technology Center at Marana Air Park, Ariz.

[2]National Wildfire Coordinating Group's S-390 Fire Behavior Course. Produced by Boise Interagency Fire Center, Joe Duft and Jerry Williams, co-chairmen of course development.

CHAPTER I

PREDICTING FIRE BEHAVIOR

The procedures for predicting fire behavior include three primary sections:

1. A means of evaluating the inputs describing the fuels, fuel moisture, windspeed, and slope.
2. A means of calculating the two basic fire descriptors—rate of spread and intensity.
3. Methods for interpreting the rate of spread and intensity to get spread distance, perimeter, area, flame length, and to identify conditions that lead to spotting and crowning. An important feature is the display of probable fire growth by time period on maps.

A diagram of how information flows through the systems is shown in figure I-1.

The primary method of interpreting the inputs is a fire model (Rothermel 1972) that has been adapted for calculation on graphs or nomograms (Albini 1976), or with a handheld TI-59 calculator and a preprogramed microchip developed by Burgan (1979).[1]

Fire spread may be thought of as a series of ignitions wherein heat from the fire raises successive strips of fuel to the ignition temperature. This principle has been explained by several authors; Thomas (1963), Anderson (1969), and Frandsen (1971).

The fire model evaluates the energy generated by the fire, the heat transfer from the fire to the fuel ahead of it, and the energy absorbed by that fuel. Because fine fuels carry the fire, the model is weighted toward such fuels—primarily material less than one-fourth inch in diameter. Both live and dead fuels are considered. Fuel moisture affects both the energy generated and the energy absorbed. Effects of wind and slope on heat transfer are included. Fuel particle size and fuel load and compactness or bulk density have a strong influence on fire behavior. The heat content, mineral content, and fuel particle density are treated as constants in this manual although they are variable within the model. Andrews (1980) offers a compilation of some of the validation studies on the fire model. Results of these studies are shown in figure I-2. Methods for verifying the procedures given in this manual in various fuel and environmental situations are offered by Rothermel and Rinehart (1983).

[1]These same procedures will work with a computer program under development tentatively named BEHAVE, as well as the tabular method of calculation being developed for the revised S-390 fire behavior course and the revised fireline handbook.

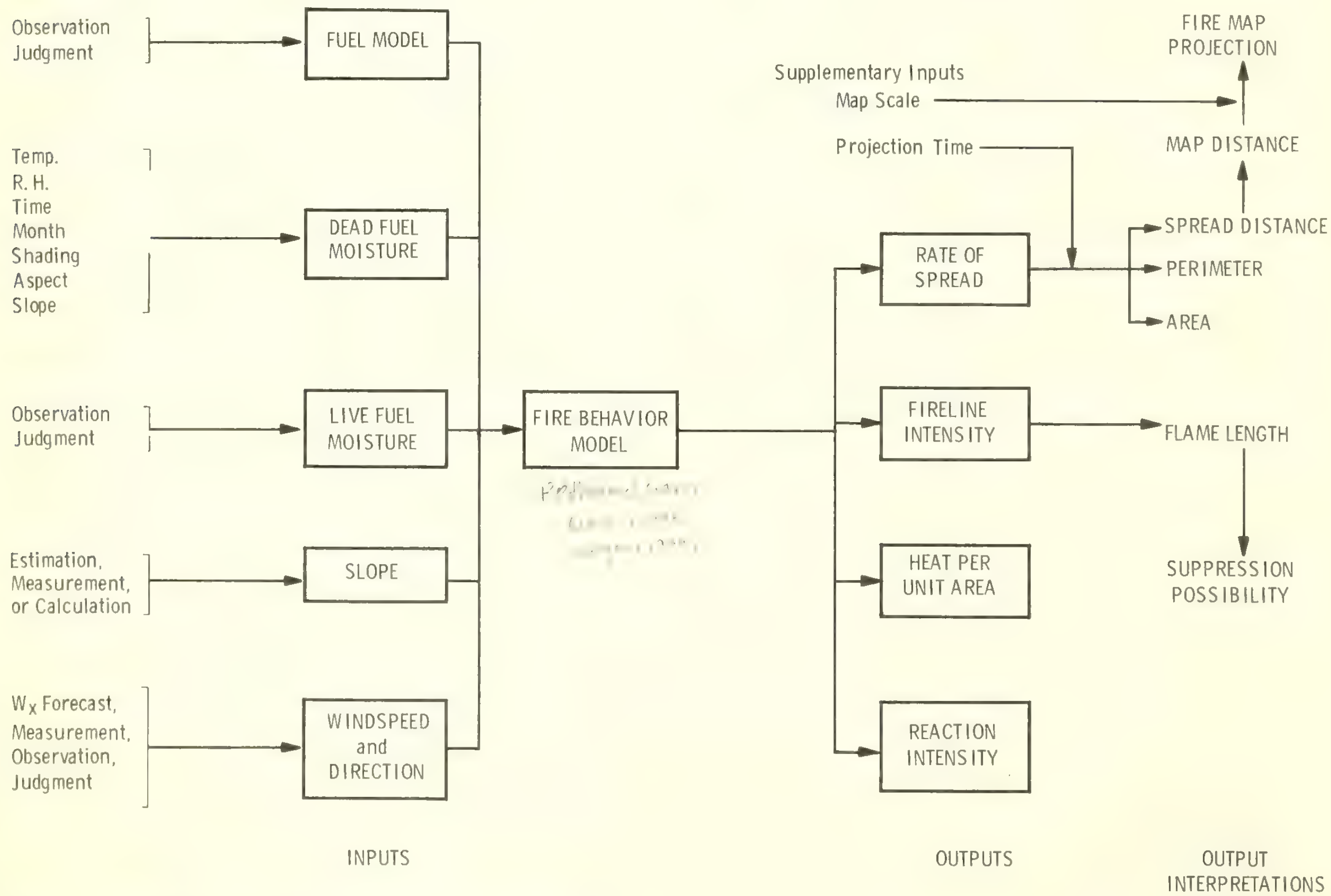


Figure I-1.—Fire behavior prediction system information flow.

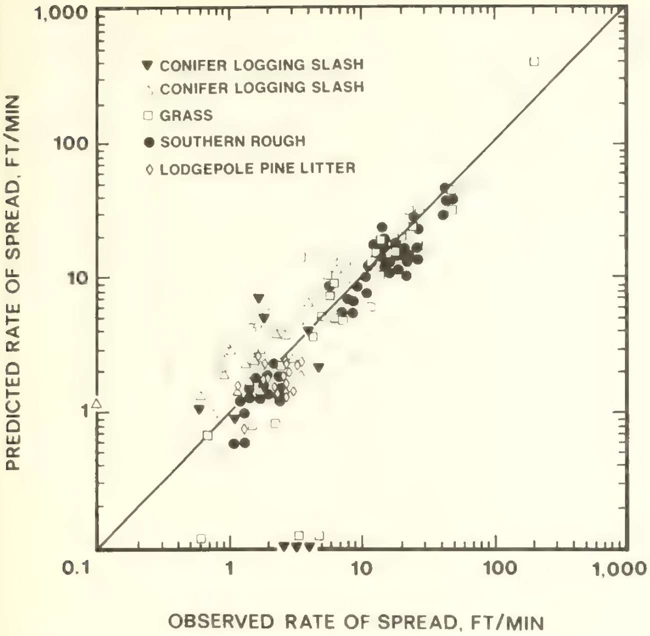


Figure I-2.—Field verification of the linear trend between predicted and observed spread rates for a wide range of fuels. The logarithmic scales dampen scatter at high spread rate while increasing it at low values. Data obtained from these sources: conifer logging slash (solid triangles), Bevins (1976); conifer logging slash (open triangles), Brown (1972); grass, Sneeuwjagt and Frandsen (1966); southern rough, Hough and Albini (1978); lodgepole pine litter, Lawson (1972).

Limitations

The fire model is primarily intended to describe a flame front advancing steadily in surface fuels within 6 feet of, and contiguous to, the ground. Typical of such fuels are dead grasses, needle litter, leaf litter, shrubs, dead and down limbwood, and logging slash. These are the fuels in which fires start and make their initial runs and in which direct attack is usually made.

The methods and model in this manual do not apply to smoldering combustion such as occurs in tightly packed litter, duff, or rotten wood.

Severe fire behavior such as crowning, spotting, and fire whirls is not predicted by the fire model. The onset of severe fire behavior, however, can often be predicted from surface fire intensity as will be explained.

Short-range firebrands may be blown ahead of the fire where they ignite fuels and increase the rate of fire spread. This mechanism is not accounted for, but the deficiency does not appear to affect the prediction of fire behavior. Short-range firebrands must ignite the fuel and start a new fire front before the fire overruns that position or the spotting will not be significant in increasing spread rate. In many cases the main fire does overrun the potential spot fires. Further, the model assumes fuels are uniform and continuous. Short-range spotting can actually compensate for the discontinuous nature of some fuels, giving extended usefulness of the model.

Although the original model was developed for uniform continuous fuels, subsequent research on nonuniform fuels (Frandsen and Andrews 1979) and the introduction of the two-fuel-model concept (Rothermel 1978)[2] permit some nonuniformity to be considered.

The methods in this manual describe the behavior at the head of the fire where the fine fuels are assumed to carry the fire. Backing fires can also be described in some cases. The burnout of fuels, usually large fuels and tightly packed litter, behind the fire front is not described.

Only the foliage and fine stems of living plants are considered fuels. When moisture content is high, such plants can dampen fire spread. When moisture content drops below a critical level, however, living plants can increase the rate of fire spread. This is accounted for by the fire model.

It is assumed that the fire has spread far enough so that it is no longer affected by the source of ignition. The system is therefore of limited usefulness in predicting behavior of prescribed fires, where the pattern of ignition is often used to control fire behavior. Nevertheless, the model is often used to plan prescribed fires by assessing the fire potential both inside and outside of the proposed burn area.

Applications

This material was drawn from a course for training fire behavior officers; therefore predictions are expressed in "real time." Predictions are keyed to a specific site, using observed weather or weather forecasts and observed fuels and topography. The material is not limited to this application, and has been adapted for other purposes, as explained in the following section.

PREDICTING FIRE BEHAVIOR

Assessing behavior of a running fire or planning strategy on a fire that has escaped initial attack is the primary use. Procedures are described in the section titled "The Fire Prediction Process." An example is given in appendix G.

DISPATCHING

When the decision has been made to suppress a newly discovered fire, the initial attack forces do not spend much time predicting fire behavior upon reaching the fire because of the urgency to direct all of their attention to suppression. Actually, it would be more useful to predict fire behavior at the dispatching office before initial attack forces are sent. Such decisions would require data on fuels, topography, and weather comparable to those needed for on-site predictions. Methods similar to those in this manual are being streamlined for such a purpose.

PLANNING

The fire prediction methods described are being used for fire management planning in many parts of the world. Although cumbersome for long-range planning, they can be effectively used for short-range and operational planning.

[2]A concept for appraising fire in nonuniform fuels. Presented at 1978 meeting on fuel and smoke management, Mt. Hood National Forest.

PRESCRIBED BURNING

Fire prediction methods can be useful when planning prescribed fires, including their containment or control, and for assessing fuel and weather conditions as burn time approaches. The methods can be used to estimate the behavior of fire that escapes the lines. Care must be used in estimating fire behavior within the burn area. The system was designed to describe the behavior of a line of fire free of influences from the drafts of other fires. Many prescribed fires are ignited in patterns intended to influence behavior: ring firing, center firing, mass firing, or strip head fires. Fires conducted for vegetation manipulation or site treatment may require burning prescriptions based on factors other than the system can provide. Experience and calibration in the fuel type can overcome some obstacles. The verification and calibration procedures given by Rothermel and Rinehart (1983) may be helpful.

MONITORING FIRES

The system is especially well suited for monitoring and predicting the behavior of fires resulting from unplanned ignitions that meet an approved prescription and, therefore, do not require immediate suppression action. Experience on the Independence Fire in Idaho in 1979 demonstrated the usefulness of anticipating the movement of a large fire burning under prescription conditions for several weeks in rugged mountain country.[3] The Forest Service categorizes these fires in planned areas as a prescribed fire from an unplanned ignition. Most agencies permit such fires to burn provided all fire behavior variables remain within the prescription developed in an approved plan. Prescribed fires in this category come closest to matching a wildfire situation. Control activities, if any, are usually confined to protecting boundaries or improvements. Additional ignitions are usually not made. Because these fires can exist through several burning periods, they offer excellent opportunities for both predicting fire behavior and verifying the prediction methods.

The Fire Prediction Process

When a fire escapes initial attack, the reinforcement forces include an overhead suppression team who will carefully assess the overall fire situation. The purpose of the prediction process, therefore, is to enable this team to estimate what a fire will do under the expected weather and existing topographic conditions. These procedures actually form a short-term planning system that uses observations of fire behavior, fuels, topography, and weather forecasts to give advanced notice of the kind of fire that can be expected. Typical steps taken in this process would be as follows:

ASSESS THE PAST AND PRESENT FIRE SITUATIONS

What has the fire done before you were able to observe it and what is it doing now? In both cases, try to determine what type of fuels the fire has been burning in, and what fuel stratum has been carrying the fire. What has the weather been? How has the fire responded to the weather in terms of intensity, rate of spread, and direction? What time of day has the fire been making runs? Has there been crowning and spotting?

DETERMINE CRITICAL AREAS

Critical areas can comprise threatened resources, cultural or natural, or fuels that can burn with high intensity or fast spread rates. Obtain and study carefully the escaped fire situation analysis (EFSA)—in some cases you may be asked to help prepare an EFSA. The EFSA will identify critical areas and thereby help identify where fire prediction estimates are needed.

WHAT INFORMATION IS NEEDED AND WHEN

Fire behavior is often predicted in response to a request from a fire officer responsible for suppression strategy or tactical plans. The prediction must be timely and presented in a form that is readily understood. Timeliness is extremely important. When an immediate estimate is requested, an elaborate answer is not expected. Estimates can be made in an amazingly short time when the procedures are understood well enough to recognize the simplifying assumptions that can be made while still retaining the significant factors. When more time is available, more elaborate predictions can be made, using maps and charts for interpretation. Remember, there is nothing as useless in the plans tent as a late fire behavior forecast.

ESTIMATE INPUTS

The greatest challenge to your professional skills on a fire will be appraising the fuels, weather, and topography. The procedures presented herein are designed to show you how to use weather information that is either received from the weather service or measured on site. The procedures are not designed to forecast weather. Where will you get your weather information? Is there a mobile weather unit on-site or ordered? Are your weather interpreting skills as sharp as they should be? Have you been following the danger rating indexes for this area? What degree of curing have the fuels experienced? Did you get a weather forecast before coming to the fire, and is there a weather change predicted? There are a number of problems to consider, and if you are not experienced in the type of fire situation in which you find yourself, try to find an experienced local person who has time to brief you on the general behavior of fires in the area, including spotting and crowning potential, fuel types and fuel maps, topography, and predictable diurnal weather conditions. The input sections elaborate on specific data needed.

CALCULATE FIRE BEHAVIOR

Either the nomograms, the TI-59 with a fire behavior CROM,[4] or the tables in the revised S-390 fire behavior course can be used to calculate rate of spread, flame length, and fireline intensity.

[3] Keown, Larry D. Fire management in the Selway-Bitterroot Wilderness, Nezperce National Forest, a report of the 1979 fire season and Independence Fire. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; May 1980.

[4] Custom Read Only Memory chip designed for predicting fire behavior that can be placed in a TI-59 calculator. Two thousand CROM's were built and distributed to fire suppression forces throughout the United States.

INTERPRET THE OUTPUTS

For new fire starts or spot fires, fire growth as an elliptical pattern on the ground can be estimated in terms of perimeter and area by time periods. If on a slope, the procedures used for predicting area and perimeter assume the wind is blowing directly upslope. The length-to-width ratio of the ellipse is governed by the windspeed and steepness of the slope.

The growth of fire from a line of fire is estimated from a series of projection points selected at strategic points along the fireline. Methods are shown for dealing with any combination of wind and slope, including fire burning upslope or backing downslope and with wind blowing either up, down, or cross-slope. The fire growth for a specified time period is then projected on a map.

Fireline intensity or flame length is used to interpret the possibility of torching, spotting, or crown fires. This, of course, must be supplemented with information about the overall fuels or timber stand condition.

FURTHER FIRE ASSESSMENT

Expected growth is extremely important in the early stages of a fire or if a weather change is forecast before fire lines are secure. As control of the fire is gradually gained, the question of the general movement of the fire is replaced with a concern for unexpected events such as spotting across control lines, fire whirls, or flareup of hot spots that may cause torching or a run through the tree crowns or unburned islands. Weather changes are often the key to this behavior. Attention is also directed to burnout and backfiring and for securing firelines. You can expect to be asked for assistance in these operations. Therefore, in the latter stages of a fire, direct your attention to the weather forecasts and the probability of these events, rather than the routine prediction of fire growth.

CHAPTER II

OBTAINING INPUTS

Many factors influence fire behavior in wildland fuels. The primary factors are fuels, weather, and topography. The influence of weather on fire behavior is expressed through fuel moisture and wind. Thus the four primary inputs to the fire model are fuels, fuel moisture, wind, and slope. Second-order variables such as temperature, humidity, shading, and sheltering operate through one of the four primary groups. These are discussed in separate sections.

To predict fire behavior by means of the fire model, descriptors of all the influencing factors must be expressed in numerical form. These inputs determine the final outputs. To avoid confusion and to maintain a record, a fire behavior worksheet is provided for recording the inputs and for calculating the results, or outputs. The worksheet, exhibit II–1, is usable with nomograms or the TI–59 calculator. Data for each calculation are recorded in one column. As the inputs are developed, they are recorded on the appropriate line described in the text. The back of the fire behavior worksheet provides a form to aid in estimating dead fuel moisture. Chapter II is devoted to describing how to assess the input values needed on the worksheet. Details on the use of the fire behavior worksheet are provided in chapter III.

Exhibit II-1.—Fire behavior worksheet.

Sheet ____ of ____

NAME OF FIRE ______________ FIRE BEHAVIOR OFFICER ______________

DATE ______________ TIME ______________

PROJ. PERIOD DATE ______________ PROJ. TIME FROM ________ to ________

INPUT DATA

								TI-59 Reg. No.
1	Projection point			____	____	____	____	
2	Fuel model proportion, %			____	____	____	____	
3	Fuel model			____	____	____	____	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	____	____	____	____	60
5	Dry bulb temperature, °F		DB	____	____	____	____	61
6	Relative humidity, %		RH	____	____	____	____	62
7	1 H TL FM, %		1H	____	____	____	____	28
8	10 H TL FM, %		10H	____	____	____	____	63
9	100 H TL FM, %		100H	____	____	____	____	30
10	Live fuel moisture, %		LIVE	____	____	____	____	33
11	20-foot windspeed, mi/h			(____)	(____)	(____)	(____)	
12	Wind adjustment factor			(____)	(____)	(____)	(____)	
13	Midflame windspeed, mi/h		M WS	____	____	____	____	79
14	Maximum slope, %		PCT S	____	____	____	____	80
15	Projection time, h		PT	____	____	____	____	81
16	Map scale, in/mi		MS	____	____	____	____	82
17	Map conversion factor, in/ch			____	____	____	____	
18	Effective windspeed, mi/h			____	____	____	____	

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	____	____	____	____	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	____	____	____	____	90
21	Fireline intensity, Btu/ft/s	[B]	INT	____	____	____	____	53
22	Flame length, ft	[R/S]	FL	____	____	____	____	54
23	Spread distance, ch	[C]	SD	____	____	____	____	42
24	Map distance, in	[R/S]	MD	____	____	____	____	43
25	Perimeter, ch	[D]	PER	____	____	____	____	40
26	Area, acres	[R/S]	AREA	____	____	____	____	89
27	Ignition component, %	[E]	IC	____	____	____	____	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	____	____	____	____	52

Exhibit II-1.— (con.) Fine dead fuel moisture calculations.

a. Projection point	____	____	____	____
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	____	____	____	____
d. Relative humidity, %	____	____	____	____
e. Reference fuel moisture, % (from table A)	☐	☐	☐	☐
f. Month	____	____	____	____
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	____	____	____	____
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	____	____	____	____
k. Slope	____	____	____	____
l. Fuel moisture correction, % (from table B, C, or D)	☐	☐	☐	☐
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	☐	☐	☐	☐
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F	____	____	____	____
o. Relative humidity, %	____	____	____	____
p. Reference fuel moisture, % (from table E)	☐	☐	☐	☐
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point	____	____	____	____
r. Aspect of site location	____	____	____	____
s. Time	____	____	____	____
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)	☐	☐	☐	☐
v. Correction for site location (L) (from table F)	☐	☐	☐	☐
w. Fuel moisture correction, % (line u - line v)	☐	☐	☐	☐
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)	☐	☐	☐	☐

Fuels

HOW FUELS ARE DESCRIBED

This section presents methods for characterizing fuels for input to the fire model. The fire model requires specific fuel information described in numerical terms. These include:

- Fuel loading – the mass of fuel per unit area, live and dead, grouped by particle size classes.
- Surface area to volume ratio of each size group.
- Fuel depth – ft
- Fuel particle density – lb/ft^3
- Heat content of fuel – Btu/lb
- Moisture of extinction – the upper limit of fuel moisture content beyond which the fire will no longer spread with a uniform front.[1]

Measuring these fuel properties is too slow for wildfire predictions. An alternative method that utilizes predescribed fuel arrangements called fuel models is provided. Fuel models have been developed that represent most surface fuels you are likely to encounter. Each fuel model contains all of the numerical values (listed above) needed by the fire spread model. The task then is to choose the most appropriate fuel model (or in the case of some nonuniform fuels, two fuel models), representing the area where fire spread is to be predicted.

[1]Moisture of extinction is dependent upon compactness of the fuel, its depth, particle size, windspeed, and slope. When conditions are favorable for burning, its effect on fire spread and intensity is low, but when conditions for burning are poor, it can cause significant changes in predicted behavior.

SELECTING FUEL MODELS

The fuel models for calculating fire behavior are those used by Albini (1976) to develop the nomograms published in his paper, "Estimating Wildfire Behavior Effects." There are 13 models, including 11 developed by Anderson and Brown and published by Rothermel (1972), a model for dead brush developed at the suggestion of Von Johnson,[2] and a model for southern rough developed by Albini. These are called the "NFFL fuel models"; or "fire behavior models." The models are described in table II-1. They are tuned to the fine fuels that carry the fire and thus describe the conditions at the head of the fire. They were developed for the time of year when fires burn well. There is no provision for changing the proportions of living and dead fuel.

Anderson (1982) describes and provides typical photographs of each of the 13 fuel models. The written descriptions are reproduced here in the section, "Fuel Model Descriptions." Anderson also provides a similarity chart for cross referencing the 13 NFFL fuel models to the 20 fuel models used in the National Fire Danger Rating System.

A key is provided to help select the model. It leads to a suggested model, which may be confirmed with Anderson's description. If the fuels are not uniform enough to describe with a single model, the two-fuel-model concept may be appropriate.

[2]Fire research scientist, then at East Lansing, Mich., who recognized the need for fuel model 6 for much of the area for which he was responsible.

Table II-1.—Description of NFFL fuel models used in fire behavior[1]

Fuel model	Typical fuel complex	Fuel loading 1 h	Fuel loading 10 h	Fuel loading 100 h	Fuel loading Live	Fuel bed depth	Moisture of extinction dead fuels
	Grass and Grass-Dominated	----------	*tons/acre*	----------		*Feet*	*Percent*
1	Short grass (1 ft)	0.74	--	--	--	1.0	12
2	Timber (grass and understory)	2.0	1.0	0.50	0.50	1.0	15
3	Tall grass (2.5 ft)	3.0	--	--	--	2.5	25
	Chaparral and Shrub Fields						
4	Chaparral (6 ft)	5.0	4.0	2.0	5.0	6.0	20
5	Brush (2 ft)	1.0	.50	--	2.0	2.0	20
6	Dormant brush, hardwood slash	1.5	2.5	2.0	--	2.5	25
7	Southern rough	1.1	1.9	1.5	.37	2.5	40
	Timber Litter						
8	Closed timber litter	1.5	1.0	2.5	--	.2	30
9	Hardwood litter	2.9	.41	.15	--	.2	25
10	Timber (litter and understory)	3.0	2.0	5.0	2.0	1.0	25
	Slash						
11	Light logging slash	1.5	4.5	5.5	--	1.0	15
12	Medium logging slash	4.0	14.0	16.5	--	2.3	20
13	Heavy logging slash	7.0	23.0	28.0	--	3.0	25

[1]Documented by Albini (1976) and Rothermel (1972).

The availability of only 13 fuel models to describe all the fuels in the United States may seem very limiting. The two-fuel-model concept, however, expands this number considerably. The two-fuel-model concept depends upon the proportional coverage of an area by two fuels. (The method is fully described in this section.)

Fire behavior estimates will be simpler if a single fuel model can be found to describe the fuels. In fact, as experience is gained from observing fires and estimating behavior, it is possible to select a fuel model, not only from a description of the physical properties of the vegetation, but also by the fire behavior characteristics it is known to produce. Experienced fire behavior officers, working in one or two fuel types, have learned to calibrate or tune the answers to more closely match fire behavior (Norum 1982). Methods for calibrating a fuel to match the behavior in a specific fuel type are provided by Rothermel and Rinehart (1983).

Considerations in Selecting a Fuel Model

1. Determine the general vegetation type, i.e., grass, brush, timber litter, or slash.
2. Estimate which stratum of surface fuel is most likely to carry the spreading fire. For instance, the fire may be in a timbered area, but the timber is relatively open and dead grass, not needle litter, is the stratum carrying the fire. In this case, fuel model 2, which is not listed as a timber model, should be considered. In the same area if the grass is sparse and there is no wind or slope, the needle litter would be the stratum carrying the fire and fuel model 9 would be a better choice.
3. Note the general depth and compactness of the fuel. This information will be needed when using the fuel model key. These are very important considerations when matching fuels, particularly in the grass and timber types.
4. Determine which fuel classes are present and estimate their influence on fire behavior. For instance, green fuel may be present, but will it play a significant role in fire behavior? Large fuels may be present, but are they sound or decaying and breaking up? Do they have limbs and twigs attached or are they bare cylinders? You must look for the fine fuels and choose a model that represents their depth, compactness, and to some extent, the amount of live fuel and its contribution to fire. Do not be restricted by what the model name is or what its original application was intended to be.
5. Using these observations, proceed through the fuel model key and the descriptions provided by Anderson (1982) to select a fuel model.
6. Record the selected fuel model on line 3 of the fire behavior worksheet.

NFFL Fuel Model Key[3]

I. PRIMARY CARRIER OF THE FIRE IS GRASS. Expected rate of spread is moderate-to-high, with low-to-moderate fireline intensity (flame length).
   - A. Grass is fine structured, generally below knee level, and cured or primarily dead. Grass is essentially continuous.
     SEE THE DESCRIPTION OF MODEL 1.
   - B. Grass is coarse structured, above knee level (averaging about 3 ft) and is difficult to walk through.
     SEE THE DESCRIPTION OF MODEL 3.
   - C. Grass is **usually** under an open timber, or brush, overstory. Litter from the overstory is involved, but grass carries the fire. Expected spread rate is slower than fuel model 1 and intensity is less than fuel model 3.
     SEE THE DESCRIPTION OF MODEL 2.

II. PRIMARY CARRIER OF THE FIRE IS BRUSH OR LITTER BENEATH BRUSH. Expected rates of spread and fireline intensities (flame length) are moderate-to-high.
   - A. Vegetative type is southern rough or low pocosin. Brush is generally 2 to 4 ft high.
     SEE THE DESCRIPTION OF MODEL 7.
   - B. Live fuels are absent or sparse. Brush averages 2 to 4 ft in height. Brush requires moderate winds to carry fire.
     SEE THE DESCRIPTION OF MODEL 6.
   - C. Live fuel moisture **can** have a significant effect on fire behavior.
     1. Brush is about 2 ft high, with light loading of brush litter underneath. Litter may carry the fire, especially at low windspeeds.
        SEE THE DESCRIPTION OF MODEL 5.
     2. Brush is head-high (6 ft), with heavy loadings of dead (woody) fuel. Very intense fire with high spread rates expected.
        SEE THE DESCRIPTION OF MODEL 4.
     3. Vegetative type is high pocosin.
        SEE THE DESCRIPTION OF MODEL 4.

III. PRIMARY CARRIER OF THE FIRE IS LITTER BENEATH A TIMBER STAND. Spread rates are low-to-moderate; fireline intensity (flame length) may be low-to-high.
   - A. Surface fuels are mostly foliage litter. Large fuels are scattered and lie on the foliage litter; that is, large fuels are not supported above the litter by their branches. Green fuels are scattered enough to be insignificant to fire behavior.
     1. Dead foliage is **tightly compacted**, short needle (2 inches or less) conifer litter or hardwood litter.
        SEE THE DESCRIPTION OF MODEL 8.
     2. Dead foliage litter is **loosely compacted** long needle pine or hardwoods.
        SEE THE DESCRIPTION OF MODEL 9.
   - B. There is a significant amount of larger fuel. Larger fuel has attached branches and twigs, or has rotted enough that it is splintered and broken. The larger fuels are fairly well distributed over the area. Some green fuel may be present. The overall depth of the fuel is probably below the knees, but some fuel may be higher.
     SEE THE DESCRIPTION OF MODEL 10.
   - C. Fuels are nonuniform, the area is mostly covered with litter interspersed with accumulations of dead and downed material (jackpots).
     SEE THE TWO-FUEL-MODEL CONCEPT.

[3]Gordie Schmidt (of R-6 and the PNW Station) has been especially helpful in reviewing and suggesting changes in the fuel model key.

IV. PRIMARY CARRIER OF THE FIRE IS LOGGING SLASH. Spread rates are low-to-high, fireline intensities (flame lengths) are low-to-very high.

A. Slash is aged and overgrown.

1. Slash is from hardwood trees. Leaves have fallen and cured. Considerable vegetation (tall weeds) has grown in amid the slash and has cured or dried out.

SEE THE DESCRIPTION OF MODEL 6.

2. Slash is from conifers. Needles have fallen and considerable vegetation (tall weeds and some shrubs) has overgrown the slash.

SEE THE DESCRIPTION OF MODEL 10.

B. Slash is fresh (0–3 years or so) and not overly compacted.

1. Slash is not continuous. Needle litter or small amounts of grass or shrubs must be present to help carry the fire, but primary carrier is still slash. Live fuels are absent or do not play a significant role in fire behavior. The slash depth is about 1 ft.

SEE THE DESCRIPTION OF MODEL 11.

2. Slash generally covers the ground (heavier loadings than Model 11), though there may be some bare spots or areas of light coverage. Average slash depth is about 2 ft. Slash is not excessively compacted. Approximately one-half of the needles may still be on the branches but are not red. Live fuels are absent, or are not expected to affect fire behavior.

SEE THE DESCRIPTION OF MODEL 12.

3. Slash is continuous or nearly so (heavier loadings than Model 12). Slash is not excessively compacted and has an average depth of 3 ft. Approximately one-half of the needles are still on the branches and are red, OR all the needles are on the branches but they are green. Live fuels are not expected to influence fire behavior.

SEE THE DESCRIPTION OF MODEL 13.

4. Same as 3, EXCEPT all the needles are attached and are red.

SEE THE DESCRIPTION OF MODEL 4.

NFFL Fuel Model Descriptions

These descriptions are taken from Anderson's book (1982) and should be used in conjunction with the fuel model key.

Grass Group

Fire behavior fuel model 1.—Fire spread is governed by the fine herbaceous fuels that have cured or are nearly cured. Fires move rapidly through cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area.

Grasslands and savanna are represented along with stubble, grass tundra, and grass-shrub combinations that meet the above area constraint. Annual and perennial grasses are included in this fuel model.

Fire behavior fuel model 2.—Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, besides litter and dead-down stemwood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third or two-thirds of the area may generally fit this model, but may include clumps of fuels that generate higher intensities and may produce firebrands. Some pinyon-juniper may be in this model.

Fire behavior fuel model 3.—Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. The fire may be driven into the upper heights of the grass stand by the wind and cross standing water. Stands are tall, averaging about 3 ft, but may vary considerably. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

Shrub Group

Fire behavior fuel model 4.—Fire intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrub, 6 or more feet tall, such as California mixed chaparral, the high pocosins along the east coast, the pine barren of New Jersey, or the closed jack pine stands of the North Central States are typical candidates. Besides flammable foliage, there is dead woody material in the stand that significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. There may be also a deep litter layer that confounds suppression efforts.

Fire behavior fuel model 5.—Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs, and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Shrubs are generally not tall, but have nearly total coverage of the area. Young, green stands such as laurel,[4] vine maple, alder, or even chaparral, manzanita, or chamise with no deadwood would qualify.

Fire behavior fuel model 6.—Fire carries through the shrub layer where the foliage is more flammable than fuel model 5, but requires moderate winds, greater than 8 mi/h at midflame height. Fire will drop to the ground at low windspeeds or openings in the stand. The shrubs are older, but not as tall as shrub types of model 4, nor do they contain as much fuel as model 4. A broad range of shrub conditions is covered by this model. Fuel situations to consider include intermediate-aged stands of chamise, chaparral, oak brush, and low pocosin. Even hardwood slash that has cured out can be considered. Pinyon-juniper shrublands may be represented, but the rate of spread may be overpredicted at windspeeds less than 20 mi/h.

Fire behavior fuel model 7.—Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammable nature of live foliage and other live material. Stands of shrubs are generally between 2 and 6 ft high. Palmetto-gallberry understory within pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

Timber Group

Fire behavior fuel model 8.—Slow-burning ground fires with low flame heights are the rule, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose

[4]Recent information indicates that laurel may be more flammable than model 5 indicates.

fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and some twigs since little undergrowth is present in the stand. Representative conifer types are white pines, lodgepole pine, spruce, fir, and larch.

Fire behavior fuel model 9.—Fires run through the surface litter faster than model 8 and have higher flame height. Both long-needle conifer and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are representative, but high winds will actually cause higher rates of spread than predicted. This is due to spotting caused by rolling and blowing leaves. Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines or southern pine plantations are grouped in this model. Concentrations of dead-down woody material will contribute to possible torching out of trees, spotting, and crowning.

Fire behavior fuel model 10.—The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead down fuels include greater quantities of 3-inch or larger limbwood resulting from overmaturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees is more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; for example, insect- or disease-ridden stands, wind-thrown stands, overmature stands with deadfall, and aged slash from light thinning or partial cutting.

Logging Slash Group

Fire behavior fuel model 11.—Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here. The less-than-3-inch material load is less than 12 tons per acre. The greater-than-3-inch material is represented by not more than 10 pieces, 4 inches in diameter, along a 50-ft transect.

Fire behavior fuel model 12.—Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash, much of it less than 3 inches in diameter. These fuels total less than 35 tons per acre and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The greater-than-3-inch material is represented by encountering 11 pieces, 6 inches in diameter, along a 50-ft transect.

Fire behavior fuel model 13.—Fire is generally carried across the area by a continuous layer of slash. Large quantities of greater-than-3-inch material are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming is sustained for long periods and firebrands of various sizes may be generated. These contribute to spotting problems as the weather conditions become more severe. Clearcuts and heavy partial cuts in mature and overmature stands are depicted where the slash load is dominated by the greater-than-3-inch material. The total load may exceed 200 tons per acre, but the less-than-3-inch fuel is generally only 10 percent of the total load. Situations where the slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

The Two-Fuel-Model Concept

If nonuniformity of the fuel makes it impossible to select a fuel model from part I, then the two-fuel-model concept may be useful.

The two-fuel-model concept is designed to account for changes in fuels in the horizontal direction, i.e., as the fire spreads, it will encounter significantly different fuels. The concept depends upon the size of the fire being large with respect to the size of the fuel arrangements causing the discontinuity. By this it is meant that the length of the fireline is long enough so that at any one time the fireline extends through both fuel types in several locations and that as the fire spreads it will encounter both fuel types repeatedly during the length of the prediction period. If this is not the case, it is likely that you will have two distinct burning conditions and the averaging process used for estimating spread rate will be meaningless. The larger the fire and the farther it travels, the larger the fuel patches can be when applying this concept.

Another consideration is that if one fuel does not make up at least 20 percent of the area, fire spread will be dominated by the other fuel and it is not worth attempting to apportion the spread rate between two fuels.

The concept assumes that horizontally nonuniform fuels can be described by two fuel models in which one represents the dominant vegetative cover over the area, and the second represents fuel concentrations that interrupt the first. For example, in a forest stand the dominant fuel strata over most of the area may be short-needle litter (fuel model 8), with concentrations of dead and down limbwood and treetops. Depending on the nature of these jackpots, they could be described by model 10 or one of the slash models, 12 or 13. An important feature of the concept is that it is not necessary to try to integrate the effect of both the needle litter and limbwood accumulation into one model. Two distinct choices can be made.

The two-fuel-model concept may also be applied to rangeland, where grass may dominate the area, along with patches of brush. Of course, the system will work vice versa, where brush is dominant, with occasional patches of grass.

The process is begun with four steps:

1. Select a fuel model from the key that represents the dominant cover—50 percent or more of the area.
2. From the key, select a fuel model that represents fuel concentrations within the area that interrupt the dominant cover.
3. Estimate the percentage of cover for the two fuels. The sum of the two should equal 100 percent.
4. Record the selected fuel models on line 3 of the fire behavior worksheet in two separate columns. Record the estimated proportional coverage of each model on line 2. This completes the information needed as inputs to the two-fuel-model concept. Calculating spread rate and interpreting intensity are explained in chapter III.

Fuel Moisture

BACKGROUND

The amount of moisture contained in wildland fuels is extremely important in determining fire behavior. The fire model utilizes fuel moisture in the determination of both fire intensity and the heat required to bring the fuel ahead of a spreading fire up to ignition temperature. The objective of this section is to provide methods for estimating fuel moisture from on-site weather measurements, or a weather forecast, or both. The moisture condition of the fine fuels is of primary importance in spreading fires. Some fuel models contain both living and dead fuels; consequently the moisture of each must be considered. In the case of live fuels, foliage moisture is of primary importance. Table II–1 and the nomograms indicate which fuel models contain live fuels.

Estimates of fuel moisture from **on-site measurements** of temperature, humidity, and shade can be made with the TI–59 CROM as described by Burgan (1979). The tabular method described here is preferred because its versatility allows estimates to be made at sites with different slope, aspect, season, and time of day, as well as from weather forecasts for locations where on-site measurements can't be made.

CAUTION: Both the tabular and TI–59 procedures for estimating fuel moisture from temperature and humidity assume that there has not been recent precipitation. If there has been precipitation, several hours of good drying are necessary before the fine fuel moisture estimates can be relied upon to be reasonable. Blackmarr (1971) has found that fine fuels that have been saturated with moisture and are drying (desorption) can be 3 to 5 percent higher in fuel moisture than fine fuels that have been dry and are gaining moisture (adsorption). If you are concerned with fuels that have been wetted recently by precipitation or dew, a correction of 3 to 5 percent may be added to the fuel moisture obtained from the procedures in this section.

Fuel moisture is simply an expression of the amount of water in a fuel component. It is standard practice to express fuel moisture as a percentage of the ovendry weight, and this is the form used to calculate fire behavior. Fuel moisture is the result of past and present weather events. Values can range as low as 1 to 2 percent in extreme drought conditions in the Southwest to more than 200 percent for live fuels. Weather affects live fuels quite differently than dead fuels; therefore methods for estimating their values are different. Live fuel moisture can range as low as 40 percent in some Southwest chaparral and the plants will still recover; however, most plants that become that dry will die. Dead fuel moistures are usually less than 30 percent. Some dead fuels in the Southeast can carry fire at 40 percent moisture, but it is unusual for fires to spread when the dead fuel moisture is that high.

Live fuel moisture values are a result of physiological changes in the plant. These are due mainly to the time of the season, precipitation events, the temperature trend, and the species. Dead fuels respond to day-to-day and hourly changes in the microclimate surrounding the fuel particle.

LIVE FUEL MOISTURE ESTIMATION

Live moisture may be evaluated in three ways:

1. Sampling and measurement.
2. From a current record of a nearby National Fire Danger Rating station.
3. Estimation from observation and a table of indicators and values.

Drying and weighing fuels is impractical for wildfire application. Moisture values in the National Fire Danger Rating System must be used with care, especially in mountainous terrain where elevation and aspect will result in moisture values far different from those taken at a valley weather station.

The favored method for quickly determining live fuel moisture at remote locations is through estimation of the stage of plant development, and the interpretations provided by table II–2. Record the value of the live fuel moisture on line 10 of the fire behavior worksheet. Note that the moisture values are spaced by large increments in the high range. This is because at high moisture values, where the live fuel will not support combustion by itself, the fire model is not as sensitive to the moisture level as it is at lower values. Above 200 percent, estimate to the nearest 100 percent; between 100 and 200 percent estimate by 50 percent; below 100 percent try to achieve 25 percent or better. Check publications that describe green fuel moisture and how it changes with the season for vegetation in your area. Many of the fuel models do not contain live fuels and it is not necessary to estimate the live fuel moisture for them.

Table II–2.— Guidelines for estimating live fuel (foliage) moisture content. Live fuel moisture is required for fuel models 2, 4, 5, 7, and 10. If data are unavailable for estimating live fuel moisture, the following rough estimates can be used

Stage of vegetative development	Moisture content
	Percent
Fresh foliage, annuals developing, early in growing cycle	300
Maturing foliage, still developing with full turgor	200
Mature foliage, new growth complete and comparable to older perennial foliage	100
Entering dormancy, coloration starting, some leaves may have dropped from stem	50
Completely cured	Less than 30, treat as a dead fuel

Example: Suppose you are in a brush area with considerable living foliage and you have chosen fuel model 5. It is early fall, the leaves are just beginning to change color, none of them have dropped, and some foliage seems in summer condition. According to table II–2, the foliage would be between 50 and 100 percent moisture content. So estimate a value of 75 percent and enter it on line 10 of the fire behavior worksheet.

Grass Fuels—Cured or Not?

The grass fuel models are preset for the time of year when burning conditions are rather severe. The grass fuels are assumed to be completely cured—that is, less than 30 percent fuel moisture. Even fuel model 2, which has a small amount of live fuel, acts as a cured grass model. The three grass models work well for cured conditions, but do not represent other times of the year when the grass is green.

DEAD FUEL MOISTURE

A unique system for classifying dead fuels uses the length of time required for a fuel particle to change moisture by a specified amount when subjected to a change in its environment. It was developed by Fosberg (1971). Dead fuels are classified on the basis of 1-, 10-, 100-, and 1,000-hour classes or response times. Fine fuels, dead foliage, and twigs, or other items usually one-fourth inch or less in diameter or thickness comprise the 1-hour time class. These fuels commonly govern the rate of spread of the fire front and are given paramount attention by the fire model. Branch wood approximately one-fourth inch to 1 inch in diameter is considered 10-hour fuel while 100-hour fuels include the range from 1 to 3 inches. One-thousand-hour fuels are 3- to 8-inch logs. They are beyond the range of consideration in the fire model and are not considered in this manual.

Because dead fuels respond to temperature, humidity, and solar radiation, we must have methods to account for these effects upon fuel moisture.[5] Temperature and humidity can be dealt with in a straightforward manner. Solar radiation is a more difficult problem, particularly in mountainous terrain, where the aspect and steepness of the slope can affect the amount of solar radiation as can the amount of shading by trees and clouds. Also, day length has an important effect. These effects are accounted for in the tables for estimating dead fuel moisture.

Estimating Fine Dead Fuel Moisture with Tables

For many fire prediction situations it is necessary to estimate fuel moisture at an inaccessible location or from a weather forecast. A set of tables,[6] specifically designed for this task, is provided. The method appears complex, but in fact consists of simply determining a reference fuel moisture for worst-case conditions, and then in another table finding a correction for the fire site or projection point. There are procedures for day or night.

The back of the fire behavior worksheet provides a form for recording data and computing moisture content of the fine fuels (1-hour TL fuels). Instructions for completing the form are explained by exhibit II-2.

The method uses temperature and relative humidity to determine a reference fuel moisture. The temperature and humidity are assumed to have been measured according to standard procedures for a weather shelter, or received in a forecast. The instructions refer to a projection point (that is, the location at which you wish to predict fire behavior) and may be at a different location from where the temperature and humidity are measured or forecast.

The remaining information needed to complete the form is used to adjust for solar heating. Note that if the projection point is more than 2,000 ft above or below the elevation where temperature and humidity are measured, these tables are not applicable. You must get another measurement closer to the projection point, get a forecast for that elevation, or use the method in appendix D for making large elevation adjustments.

Also note that the time of measurement or forecast should lie within the same time period that the fire prediction is made. The tables by themselves are not used for making moisture estimates for some future time.

Estimates for valley bottoms (taken from column B in table F) are for inversion conditions. Cold air draining into a steep, narrow valley accumulates to form a pool of cold, damp air that can fill the valley to a considerable depth. This condition needs a substantial correction added to the moisture conditions at a dry site above the valley floor.

The tables may be used to adjust the moisture of fuels in valley bottoms from conditions measured on the slopes above, but do not use weather data taken beneath a valley inversion and attempt to infer fuel moistures at drier sites upslope. The corrections are too large and uncertain, and you may get meaningless results.

When extreme inversions do not exist, and the air is being mixed by general winds (downslope winds will not cause mixing), use the nighttime reference fuel moisture without correction for elevation. The corrections are for solar radiation and are not applicable at night.

If you are using nomograms to estimate fire behavior, only one dead fuel size is necessary and the adjusted value for fine fuels taken from the tables may be used directly. If larger fuels are present and are noticeably wetter than the fine fuels, then the fine fuel moisture can be adjusted to account for this effect on fire spread. This will usually occur in a drying trend because large fuels dry slower and remain wetter than the fine fuels. The adjustment should not be great unless large fuels dominate the complex. Experience with your fuels is necessary to determine the right amount of adjustment.

If the TI-59 calculator and CROM are being used, fuel moisture values obtained from the tables are entered on line 7 of the fire behavior worksheet. The calculator will estimate a 10-hour fuel moisture value from the temperature/humidity and 1-hour moisture value. To do this it is only necessary to store a zero for 10-hour fuel moisture before the calculations are begun. If you are uncertain about how to calculate 10-hour moisture with the calculator, a first approximation can be made by adding 1 percent to the 1-hour value for 10-hour fuels and 2 percent to the 1-hour value for the 100-hour fuel moisture. Enter the 10-hour fuel moisture on line 8, and the 100-hour fuel moisture on line 9.

[5]Blackmarr (1971) presents fuel moisture data for several fuel types found in the Southeast.

[6]The unpublished tables presented here were developed from work initiated by Steve Sackett at the Rocky Mountain Station and later modified by Bob Burgan and Jack Cohen at the Intermountain Station. Tables simplified for rapid field use are given in the field handbook for the S-390 fire behavior course.

Exhibit II-2. **Guidelines for fine dead fuel moisture calculations worksheet.**

For each fire behavior projection point, it is necessary to include a fine, dead fuel moisture. Following is a line by line description of the worksheet to be used in calculating the appropriate fuel moisture input to the fire behavior model. This worksheet is printed on the reverse side of the fire behavior worksheet.

Values that describe conditions are either recorded on a blank line or a code letter is circled. Values that are read from tables or calculated are recorded in boxes.

		PROCEDURES
a. Projection point	______	Record the number of the projection point for which a fire behavior prediction is to be made. This corresponds to the number recorded on line 1 of the fire behavior worksheet.
b. Day or night (D/N)	D/N	Daytime projections are for 0800-1959. Nighttime projections are for 2000-0759. Circle the appropriate letter. If day, complete lines c through m. If night, complete lines n through w.
DAYTIME CALCULATIONS		Daytime calculations use c through m.
c. Dry bulb temperature, °F	______	Dry bulb temperature is determined for the time period in question either by measurement or forecast. The site location may or may not be at the projection point. Record temperature, °F.
d. Relative humidity, %	______	Record relative humidity for the time period in question.
e. Reference fuel moisture, % (from table A)	[ ]	Go to table A. Determine reference fuel moisture percent from the intersection of temperature and relative humidity shown on lines c and d. Record reference fuel moisture, percent.
f. Month	______	Record the month in question. This determines whether table B, C, or D is used.
g. Exposed or shaded (E/S)	E/S	Determine whether fine dead fuels ahead of projection point is EXPOSED (<50%) to solar radiation, or SHADED (≥50%) from solar radiation. This can be due to cloud cover and/or canopy cover. Circle appropriate letter.
h. Time	______	Record the expected time when the projection point will be used to estimate fire behavior. This should correspond to the time recorded in the heading of the fire behavior worksheet. The temperature/RH forecast or measurement must be for the same time period as the projection time point.
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	Record the elevational difference between the location of the projection point and temperature/RH site location. If the difference is ±1000' circle L (site location); 1000'-2000' above, circle A (above location); 1000'-2000' below circle B (below location). If the projection point is more than 2000' above or below the temperature/RH site location, get a new forecast or reading.
j. Aspect	______	Record the aspect of the projection point location.
k. Slope	______	Record the slope percent at the projection point location
l. Fuel moisture correction, % (from table B, C or D)	[ ]	From information on lines f, g, h, i, j, and k, determine appropriate daytime correction table (B, C, or D).
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	[ ]	Record the sum of lines e and l. The fine dead fuel moisture percent is determined by adding the fuel moisture correction to the reference fuel moisture. This value is transferred to line 7 of the fire behavior worksheet.

Fine dead fuel moisture corrections.

		PROCEDURES
NIGHTTIME CALCULATIONS		Nighttime calculations use lines n through x.
n. Dry bulb temperature, °F	______	Dry bulb temperature is determined for the time period in question either by measurement or forecast. The site location may or may not be at the projection point. Record temperature, °F.
o. Relative humidity, %	______	Record relative humidity for the time period in question.
p. Reference fuel moisture, % (from table E)	[ ]	Go to table E. Determine reference fuel moisture percent from the intersection of temperature and relative humidity shown on lines n and o. Record reference fuel moisture, %.
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.		If a strong inversion exists and a correction must be made for elevation or aspect change, continue with lines q through x. Otherwise record the value from p on line x.
q. Aspect of projection point	______	Record the aspect of the projection point.
r. Aspect of site location	______	Record the aspect of the temperature/RH site location.
s. Time	______	Record the expected time when the projection point will be used to estimate fire behavior. This should correspond to the time recorded in the heading of the fire behavior worksheet. The temperature/RH forecast or measurement must be for the same time period as the projection point time.
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	Record the elevational difference between the location of the projection point and temperature/RH site location. If the difference is ±1000' circle L (site location); 1000'-2000' above, A (above location); 1000'-2000' below, B (below location). If the projection point is more than 2000' above or below the temperature/RH site location, get a new forecast or reading.
u. Correction for projection point location (from table F)	[ ]	Go to table F. Use the information on lines q, s, and t to determine the moisture correction for the projection point.
v. Correction for site location (L) (from table F)	[ ]	Go to table F. Use L and the information on lines r and s to determine the moisture correction for the temperature/RH site location.
w. Fuel moisture correction, % (line u - line v)	[ ]	Determine the difference between the projection point correction and the site location correction. Subtract line v from line u. Record the difference as + or -.
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)	[ ]	Determine the fine dead fuel moisture by applying the fuel moisture correction to the reference fuel moisture. Line w is added to line p (watch the sign of line w). This value is transferred to line 7 of the fire behavior worksheet.

Exhibit II-2.(con).

TABLE A

REFERENCE FUEL MOISTURE

DAY TIME
0800-1959

Dry Bulb Temperature (°F)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
	RELATIVE HUMIDITY (PERCENT)																				
10 - 29	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
30 - 49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
50 - 69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
70 - 89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
90-109	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
109+	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	12

GO TO TABLE B, C, or D FOR CORRECTIONS

TABLE B

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

MAY JUNE JULY

		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS																			
N	0-30%	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
N	31%+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30%	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
E	31%+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30%	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
S	31%+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30%	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
W	31%+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	0%+	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	0%+	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	0%+	4	5	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

TABLE C

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

FEBRUARY MARCH APRIL/AUGUST SEPTEMBER OCTOBER

		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5
	31%+	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5
E	0-30%	3	4	5	1	2	3	1	1	1	1	1	2	1	2	3	3	4	5
	31%+	3	3	4	1	1	1	1	1	1	1	2	3	3	4	5	4	5	6
S	0-30%	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5
	31%+	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5
W	0-30%	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5
	31%+	4	5	6	3	4	5	1	2	3	1	1	1	1	1	1	3	3	4
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6
E	0%+	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6
S	0%+	4	5	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6
W	0%+	4	5	6	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

TABLE D

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

NOVEMBER DECEMBER JANUARY

		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6
	31%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0-30%	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6
	31%+	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6
S	0-30%	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6
	31%+	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6
W	0-30%	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6
	31%+	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
S	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
W	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

TABLE E

REFERENCE FUEL MOISTURE

NIGHT TIME
2000-0759

RELATIVE HUMIDITY (PERCENT)

Dry Bulb Temperature (°F)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

TABLE F

NIGHT TIME
2000-0759

DEAD FUEL MOISTURE CONTENT CORRECTIONS

	2000 ➤			2200 ➤			0000 ➤			0200 ➤			0400 ➤			0600 ➤		
	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N+E	9	1	1	13	1	2	16	2	2	17	1	1	18	1	1	16	2	1
S+W	9	0	1	14	0	1	16	0	2	17	0	1	18	0	0	9	0	1

NOTE: A = 1000'-2000' above size
L = ±1000' of site location
B = 1000'-2000' below site

Following are two examples in which fine dead fuel moisture is calculated. The work is shown on the accompanying calculation forms.

Example 1: Calculate the dead fuel moisture given the following conditions:

Daytime	
Dry bulb temperature	- 80° F
Relative humidity	- 20%
Slope	- 35%
Aspect	- North
Site exposure	- Open
Month	- August
Time	- 1300
Sky	- Clear

(a) What is the dead fuel moisture at your location?

(b) What is it 1,200 ft lower on an east aspect with the same slope?

(c) What is it at your location if the sky is cloudy or there is a forest canopy?

Solution 1: (a) 6%
(b) 4%
(c) 7%

Example 2: Calculate the dead fuel moisture given the following conditions:

Nighttime	
Dry bulb temperature	- 60° F
Relative humidity	- 50%
Aspect	- North
Time	- 2300

(a) What is the dead fuel moisture at your location?

(b) What is it 700 ft higher on a south slope?

(c) If a strong inversion exists and you are located in the thermal belt, what is the dead fuel moisture 1,500 ft lower (in valley bottom) on the same slope?

Solution 2: (a) 10%
(b) 9%
(c) 22%

Wind[7]

Wind is the most variable factor required to predict fire behavior. It not only changes with time, but also in horizontal and vertical directions. This section tells how to interpret wind information obtained from forecasts or from on-site measurements into inputs for calculations. The procedures deal with the problem of interpreting wind variation over horizontal and vertical space as influenced by topography, vegetation (including trees), and type of wind. The problem of wind variation and how to cope with it during a prediction period is discussed further in the chapter on predicting fire growth from a line of fire.

Many types of wind exist, and most have a repeatable pattern that must be identified to make reliable predictions. Others are not reliable, but since they can strongly influence fire behavior they must be considered. Such winds include winds accompanying thunderstorms, whirlwinds, and nighttime high elevation winds, and are labeled "spurious winds." You may wish to add other winds in your locality to this group. For winds that are predictable, general winds and convective winds, the procedures lead to estimation of the windspeed and direction at the midflame height in surface fuels.

The fire model was developed to predict fire spread based upon the wind that would be present without influence from a fire. This greatly simplifies the problem of fire prediction because it is not necessary to predict the fire's influence upon the wind and allows a forecast to be used for predicting fire behavior. This excludes predictions in severe fire situations for which the fire model was not designed, such as running crown fires or many prescribed fire situations where in-drafts are relied upon to control fire behavior.

The standard height for wind measurements used by land management agencies in this country is 20 ft above the surface, adjusted for vegetation depth (Fischer and Hardy 1976). Most fires in surface fuels burn below the 20-ft height, and since wind is slowed significantly by friction near the surface, the 20-ft windspeed must be adjusted to obtain the correct value for predicting fire behavior. The nomograms published by Albini (1976) have a built-in correction that reduces the 20-ft windspeed by one-half to obtain the midflame windspeed. This is a good approximation for exposed fuels, but will cause overprediction of fire spread in some fuels sheltered by an overstory of trees (Albini and Baughman 1979). The 1978 fire behavior officers' course introduced nomograms revised to use midflame windspeed as the input and to provide a method of inferring midflame windspeed based on the sheltering conditions. These procedures are used in this manual.

WIND INFORMATION REQUIRED FOR PREDICTING SPREAD

The wind input value is the estimated windspeed and wind direction at a height above the surface fuel equivalent to the mid-level height of flames. This information is needed at locations around the fire perimeter where fuels, topography, or microclimate are expected to cause significantly different fire behavior. These locations are known as projection points. Usually two or three projection points are sufficient to estimate the general growth of a fire. The wind estimates should be made for time periods when the wind can be expected to remain reasonably stable. Selection of projection points is further explained in chapter IV.

SOURCES OF WIND INFORMATION

In wildfire situations you must be prepared to use the data available. A fire weather forecast is the best source of wind information. The National Weather Service has special fire weather forecasts available for many areas of the country during the fire season. The areas covered and the service centers are shown in figure II-1. On large project fires in the western United States, one may request a mobile unit and forecaster to come to the fire site. Experience has shown that communications with the forecaster will break down when you depart to a fire and for several hours after you arrive at the scene. The procedures in this section assume that soon after the initial stage of the fire you will reestablish direct access to a forecaster either by phone, radio, or on-site. To facilitate communications with the forecaster, the Fire Weather Special Forecast Request form is available (exhibit II-3). (Instructions are printed on the back of the form.) The form is used to record all meteorological data, not just wind. It also provides for documenting weather observations near the fire site to aid the forecaster.

[7]The section on "Wind" has changed drastically since it was first taught in 1976. I wish to express sincere appreciation to Clyde O'Dell for repeatedly reformulating the lesson plan; to Frank Albini, Bob Baughman, John Deeming, Jack Cohen, and Don Latham for contributing to modeling of this difficult subject; and to Dave Goens, Frank Gift, John Deeming, and Rod Norum for review and critique.

	Example			
a. Projection point	1a	1b	1c	
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	80	80	80	
d. Relative humidity, %	20	20	20	
e. Reference fuel moisture, % (from table A)	3	3	3	
f. Month	Aug	Aug	Aug	
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	1300	1300	1300	
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	N	E	N	
k. Slope	35	35	35	
l. Fuel moisture correction, % (from table B, C, or D)	3	1	4	
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	6	4	7	
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location(from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FINE DEAD FUEL MOISTURE CALCULATIONS

	Example			
a. Projection point	2a	2b	2c	
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F				
d. Relative humidity, %				
e. Reference fuel moisture, % (from table A)				
f. Month				
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time				
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect				
k. Slope				
l. Fuel moisture correction, % (from table B, C, or D)				
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)				
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F	60	60	60	
o. Relative humidity, %	50	50	50	
p. Reference fuel moisture, % (from table E)	10	10	10	
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point	N	S	N	
r. Aspect of site location	N	N	N	
s. Time	2300	2300	2300	
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)	1	0	13	
v. Correction for site location (L) (from table F)	1	1	1	
w. Fuel moisture correction, % (line u - line v)	0	-1	12	
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)	10	9	22	

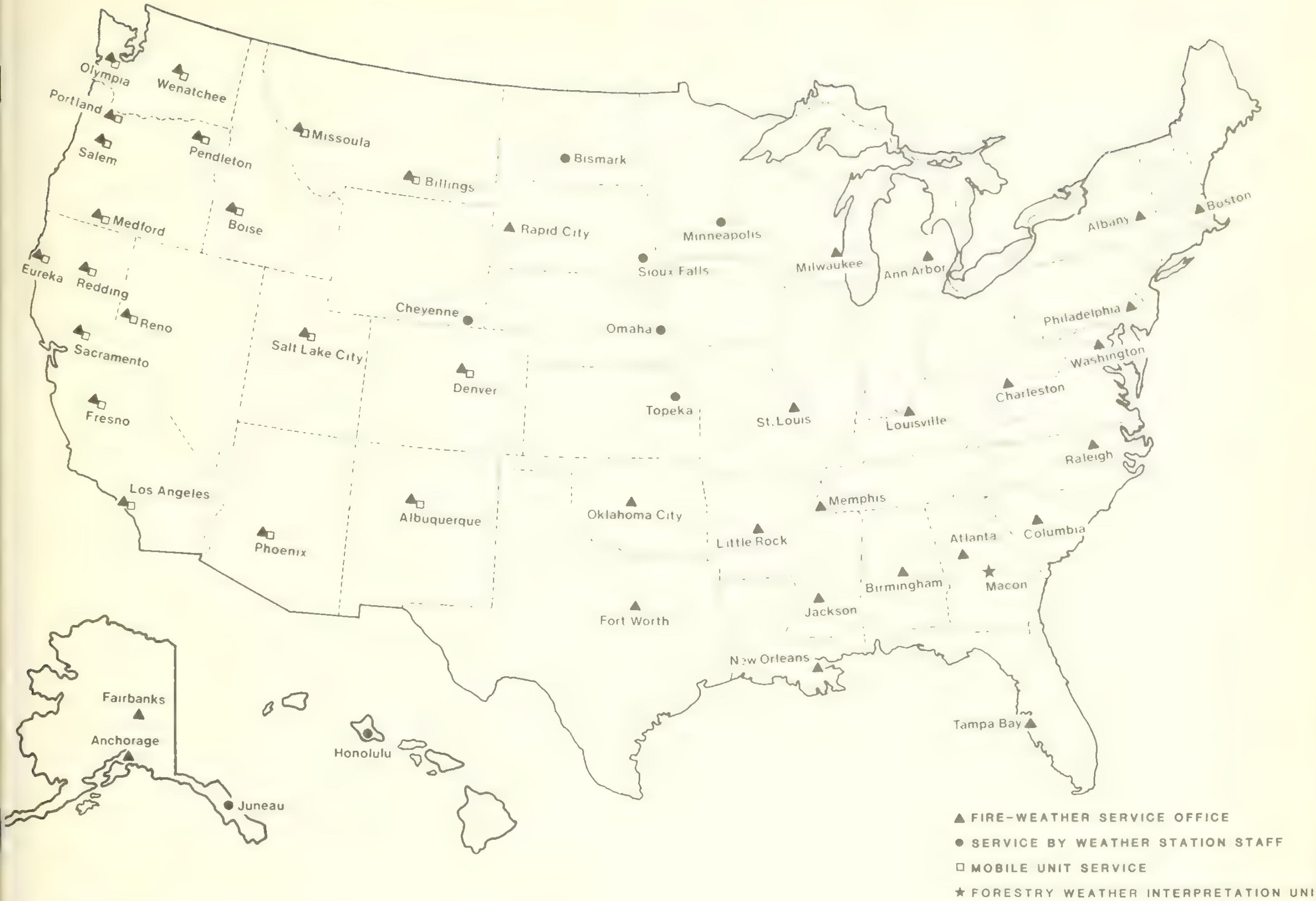


Figure II-1.—Offices participating in fire weather program.

Visit your forecast center and discuss reporting procedures and the type of data you will need.

Weather measurements taken on-site must be used carefully. If the fire extends over several days, an array of data from around the fire can be compiled to aid in predicting windspeed, direction, time of change, and periods of persistence. The location of the measurement must be reconciled with the fire location. Data taken on ridges or mountain passes may have little direct relationship to a fire that is sheltered by topography. If these measurements are carefully documented by time of day, from locations that include valley bottoms as well as midslope and ridges, a pattern of wind behavior can emerge. With this data, the meteorological procedure called persistence forecasting can be used. The best estimate of expected weather, and more particularly wind, is that it will repeat the pattern of the preceding day if the general synoptic weather pattern does not change. Persistence forecasting should be used only when you have assurance from the fire weather forecaster that the general synoptic weather pattern will persist.

There are times when an immediate fire behavior prediction is needed for making an on-the-spot prediction or revising an old prediction. For these cases, an eye-level measurement of the windspeed can be taken at a location upwind of the fire at a distance equivalent to at least 20 flame lengths, or on the flank of the fire. Wind measurement must be practiced. The standard time for averaging windspeed measurements is 10 minutes (Fischer and Hardy 1976). Direct reading anemometers, such as the pith-ball type supplied in the belt weather kit, are impossible to average over such a long time period. Observe the anemometer for at least 2 minutes and select a speed at about the upper two-thirds between the high and low indications. That is, if the readings vary between 5 and 10 mi/h, select 8 mi/h as the representative windspeed. Repeat the reading periodically to see if the wind is increasing, decreasing, or unchanged. Crosby and Chandler (1966) give an excellent discussion of the problems of measuring windspeed with a handheld anemometer.

If an anemometer is not available, the modified Beaufort scale developed by Jemison (1934) may be used. The Beaufort scale provides estimates of windspeed based on the effect of wind upon natural surroundings. These should be considered as 20-ft winds. The scale works in wind ranges and is shown by table II-3. If unable to get close to the fire, data can be used from a location that is similar in regard to slope, aspect, elevation, and sheltering. Such measurements and estimates can be made and applied quickly without the elaborate procedures necessary to interpret a forecast described in this manual. On-site measurements are further discussed by Rothermel and Rinehart (1983).

Exhibit II-3.—Example of Fire Weather Special Forecast Request.

FIRE WEATHER SPECIAL FORECAST REQUEST

(See reverse for instructions)

I. REQUESTING AGENCY WILL FURNISH:

1. NAME OF FIRE OR OTHER PROJECT	2. CONTROL AGENCY	3. REQUEST MADE TIME†	DATE
Rock Creek Burn	Gallatin N.F.	1100 MDT	9/3/8X

4. LOCATION (By ¼ Sec · Sec · Twp · Range)	5. DRAINAGE NAME	6. EXPOSURE (NE, E, SE, etc.)
T 7S R6E S 14 & 15	Rock Creek	SE

7. SIZE OF PROJECT (Acres)*	8. ELEVATION* TOP	BOTTOM	9. FUEL TYPE	10. PROJECT ON:
600 A	7400	6000	Sage/grass, pockets brush/aspen	x GROUND ☐ CROWNING

11. WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS *(See example on reverse)*

PLACE	ELEVATION	OB TIME†	WIND DIR.-VEL. 20 FT.	WIND DIR.-VEL. EYE LEVEL	TEMP. DRY	TEMP. WET	‡(Leave blank) RH	‡(Leave blank) DP	REMARKS (Indicate rain, thunderstorms, etc. Also wind condition and 10ths of cloud cover)
Site 1	7380	1040		SW 8	60	46	37	34	Clear
Site 2	6000	1045		W 2/3	52	43	50	34	Clear
Car-bella	5000	Yesterday 1330	S 8		69	51	29	36	10-H FM 10% clear

12. SEND FORECAST TO:	PLACE	VIA	ATTN: (Name, if applicable)
	Dispatch Bozeman	Teletype	Larry Keown

II. FIRE WEATHER FORECASTER WILL FURNISH:

13. FORECAST AND OUTLOOK **TIME† AND DATE:** 9/4/80 1122 MDT

(SPECIFY WIND - 20 FOOT OR EYE LEVEL)

This afternoon. . . Sunny, little warmer and drier.
Maximum temperature at 6000' - 75 Minimum humidity at 6000' - 24
Maximum temperature at 7400' - 70 Minimum humidity at 7400' - 26

Eye level winds . . . light upslope (S'ly) 3-5 mi/h mid slopes and top. Light and variable bottom at noon becoming upslope (south) 8-12 mi/h mid-through late afternoon. Very good smoke dispersal to 16,000 ft. MSL afternoon. Winds aloft 12,000 ft. Southwest 18 mi/h.

Tonight . . . Clear with good, rapid temperature and humidity recovery.

Outlook for tomorrow . . . Sunny, not much change temperature and humidity. Decreasing southwesterly winds aloft.

NAME OF FIRE WEATHER FORECASTER	FIRE WEATHER OFFICE
Paterson	NWS, Billings, MT

III. REQUESTING AGENCY WILL COMPLETE UPON RECEIPT OF FORECAST

IV. FORECAST RECEIVED:	TIME†	DATE	NAME

Explanation of Symbols:
- † Use 24-hour clock to indicate time. Example: 10:15 p.m. = 2215; 10:15 a.m. = 1015.
- * For concentrations (as groups of lightning fires) specify "Concentration"; then give number of fires and size of largest. If concentrations are in more than one drainage, request special forecast for each drainage.
- ‡ No entry necessary. To be computed by the Fire Weather Forecaster.

Table II-3.— Modified Beaufort scale for estimating 20-ft windspeed

Wind class	Range of speeds	Nomenclature
	Mi/h	
1	≤ 3	Very light – smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branchlets and twigs of trees move gently; tall grasses and weeds sway and bend with wind; wind vane barely moves.
2	4–7	Light – trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag.
3	8–12	Gentle breeze – trees of pole size in the open sway very noticeably; large branches of pole-size trees in the open toss; tops of trees in dense stands sway; wind extends small flag; a few crested waves form on lakes.
4	13–18	Moderate breeze – trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road.
5	19–24	Fresh – branchlets are broken from trees; inconvenience is felt in walking against wind.
6	25–31	Strong – tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage to buildings.
7	32–38	Moderate gale – severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
8	≥ 39	Fresh gale – surfaced strong Santa Ana; intense stress on all exposed objects, vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path.

INTERPRETING WINDS

Because windspeed and wind direction are required at the midflame level, which is close to the ground and comparatively remote from overhead synoptic conditions, the influence of topography, vegetative sheltering, local heating or cooling, and surface friction must be considered. Fortunately, methods for interpreting these effects are available and can be applied if the type of wind or its driving force is known. Furthermore, there is an order to the expected dominance of wind type, according to the associated conditions, such as time of day, topographic conditions, stability of the atmosphere, and so on.

Wind characteristics near the ground depend upon its vertical depth and the forces that drive the wind. If the airflow is deep, as would be expected with local winds generated from general winds aloft, surface friction will slow the air nearest to the surface and produce a velocity profile as shown in figure II–2. Note that the windspeed continually increases with height above the surface until it reaches a constant value. If the speed at some height is known and the shape of the curve is known, then the windspeed at some lower height can be estimated. The shape of this curve has been studied extensively and a method for estimating windspeed at midflame level has been developed by Albini and Baughman (1979) and Baughman and Albini (1980). Their method also accounts for the sheltering effect of forest cover. Application of this research is presented in step 7 of procedures that follow in this section.

If the wind is generated by differential heating between air near a heated slope and air above the influence of surface heating, then convective slope winds are produced. The velocity profile for this wind (fig. II–3) is different than for winds that have large vertical depths. This flow is described by Albini, Latham, and Baughman (1982). Application of this research is presented in step 8 of the procedures.

From this discussion we can see that the type of wind driving the fire is very important and must be known to make proper interpretation of the midflame windspeed. Before proceeding, a review of the types of winds to be considered is necessary. For a complete review, study carefully U.S. Department of Agriculture Handbook No. 360 by Schroeder and Buck (1970). The comments given below on wind types are taken from their book, with some editorial changes.

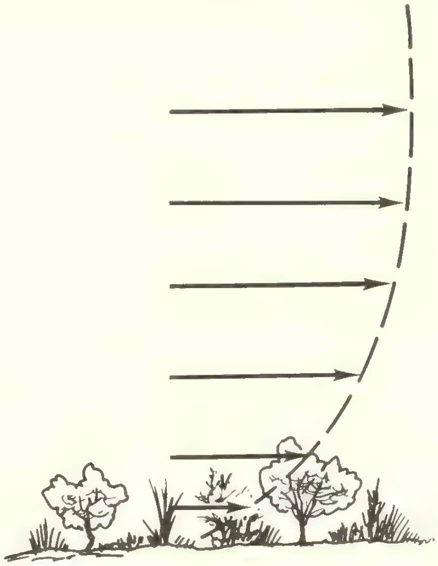


Figure II-2.—General wind velocity profile near surface.

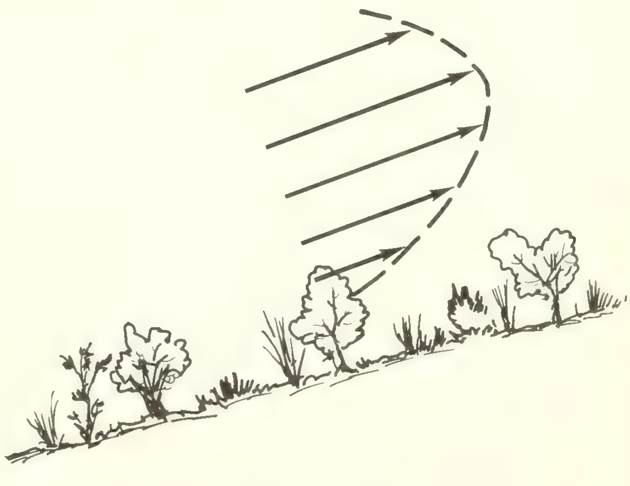


Figure II-3.—Velocity profile of upslope convective winds.

General Winds

"General winds" are produced by the broadscale pressure gradients that are shown on synoptic weather maps. They vary in speed and direction as the synoptic-scale highs and lows develop, move, and decay. General winds will often be referred to as winds aloft, or free-air winds. They are also referred to as frontal winds. Fronts are most commonly thought of in association with precipitation and thunderstorms. But occasionally fronts will cause neither. In these instances, the winds accompanying the frontal passage may be particularly significant to fire behavior.

General winds are usually separated into surface winds and winds aloft. There is no sharp distinction between them, but rather a blending of one into the other. In ascending from the surface through the lower atmosphere, there is a transition in both speed and direction from the surface to the top of the friction layer, which is also called the mixing layer. The depth of this friction or mixing layer depends upon the velocity of the winds aloft, roughness of the terrain, and the intensity of heating or cooling at the surface. The winds aloft above the mixing layer are steadier in speed and direction, but they do change as pressure centers move and change in intensity.

Wildland fires of low intensity may be affected only by the airflow near the surface. When the rate of combustion increases, however, the upper airflow becomes important as an influence on fire behavior. Airflow aloft may help or hinder the development of deep convection columns. It may carry burning embers that ignite spot fires some distance from the main fire. The winds aloft may be greatly different from the surface winds in speed and direction.

Mountains represent the maximum degree of surface roughness and thus provide the greatest friction to low-level airflow. Mountains and their associated valleys provide important channels that establish local wind direction resulting from general winds aloft. Airflow is guided by the topography into the principal drainage channels. General winds blowing across mountain ridges are lifted along the surface to the gaps and crests. If the air is stable, it will increase in speed as it crosses the ridge. Ridgetop winds thus tend to be somewhat stronger than winds in the free air at the same level.

Eddy currents are often associated with bluffs and similarly shaped canyon rims. When a bluff faces downwind, air on the lee side is protected from the direct force of the wind flowing over the rim. If the wind is persistent, however, it may start to rotate the air below and form a large, stationary roll eddy. This often results in a moderate to strong upslope wind opposite in direction to that flowing over the rim. Eddies of this nature are common in the lee of ridges that break off abruptly, and beneath the rims of plateaus and canyon walls.

The variability of general surface winds is somewhat greater during the spring and fall fire seasons in eastern portions of the continent than it is during the summer fire season of the mountainous West. Pressure systems move more frequently and rapidly in the East than in the West. In the western United States, the major mountain chains tend both to hinder the movement of organized highs and lows and to lift winds associated with them above much of the topography. Strong surface heating in summer also diminishes the surface effects of these changes.

Foehn Winds

Foehn winds represent a special type of local wind associated with mountain systems. In most mountain areas, local winds are sometimes observed to flow over the mountain ranges and descend the slopes on the leeward side. If the down-flowing wind is warm and dry, it is called a foehn wind. The development of a foehn wind requires a strong high-pressure system on one side of the mountain range and a corresponding low, or trough, on the other side.

Such pressure patterns are most common to the cool months. Therefore, foehn winds are more frequent in the periods from September through April than during summer months.

Foehn winds have local names such as Chinook, East winds, North and Mono winds, and Santa Ana winds. They have been carefully studied in the West, and a person working in these areas should become familiar with their expected behavior.

Convective Winds

Slope Winds

Slope winds are local diurnal winds, which occur on all sloping surfaces. They flow upslope during the day as a result of surface heating, and downslope at night because of surface cooling. Slope winds are produced by the local pressure gradient caused by the difference in temperature between air near the slope and the air at the same elevation away from the slope. Upslope winds are quite shallow, but their depth increases from the lower portion of the slope to the upper portion (fig. II-4). The depth of this turbulent layer increases as it

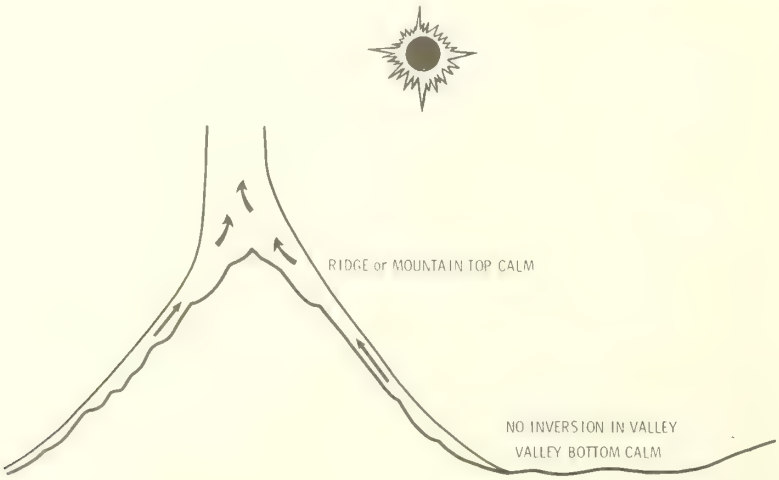


Figure II-4.—Conditions for upslope convective winds.

approaches the top of the slope, where it leaves the slope and vents vertically. Upslope velocities from solar heating will seldom exceed 8 to 10 mi/h at the standard 20-ft height. The shape of the velocity profile for upslope convection winds is shown in figure II-3.

The transition from upslope to downslope wind begins soon after the first slopes go into afternoon shadow and surface cooling begins. In individual draws and on slopes going into shadow, the transition period consists of (1) dying of the upslope wind, (2) a period of relative calm, and then (3) gentle laminar flow downslope. Downslope winds are very shallow, with slower speeds than upslope winds. The cool, denser air is stable and the downslope flow therefore tends to be laminar. Cool, dense air accumulates in the bottom of canyons and valleys, creating an inversion which increases in depth and strength during the night hours.

Valley Winds

Valley winds are diurnal winds that blow up-valley by day and down-valley by night. They are the result of differences in temperatures between air in the valley and air at the same elevation over the adjacent plain (or larger valley). Air in the small, high valleys is heated by contact with the slopes, and the resulting slope wind circulation is effective in distributing the heat through the entire mass of valley air. As the valley air becomes warmer and less dense than the air over the plain, a local pressure gradient is established from the plain to the valley and an up-valley wind begins.

Whereas upslope winds begin within minutes after the sun strikes the slope, the up-valley wind does not start until the whole mass of air within the valley becomes warmed. This is usually in middle or late forenoon, depending on the size of the valley. The up-valley wind reaches its maximum speed in the early afternoon and continues into the evening. Up-valley windspeeds in larger valleys are ordinarily 10 to 15 mi/h. The transition from up-valley to down-valley flow takes place in the early night. The time of transition depends on the size of the valley or canyon and on factors favoring cooling and the establishment of a temperature differential. The transition takes place gradually. First, a downslope wind develops on the slopes surrounding the valley, which deepens during the early night, becoming the down-valley wind. The down-valley wind may be thought of as the exodus or release of the dense air pool created by cooling along the slope. Down-valley speeds are normally less than up-valley—6 to 8 mi/h, reaching their maximum by early morning.

Sea Breezes

The surface sea breeze begins around mid-forenoon, strengthens during the day, and ends around sunset, although the times can vary considerably because of local conditions of cloudiness and the general winds. The breeze begins at the coast and gradually pushes farther and farther inland during the day, reaching its maximum penetration about the time of maximum temperature. Strong general winds produce mechanical mixing, which tends to lessen the temperature difference between the land and the sea surfaces; thus the sea breeze component becomes weak and only slightly alters the general wind flow. In the East, land and sea breezes are most pronounced in late spring and early summer when land and water temperature differences are greatest, and they taper off toward the end of the warm season as temperature differences decrease.

The Pacific sea breeze is characterized by considerable thermal turbulence and may extend inland 30 to 40 miles or more from the water under favorable conditions. The depth of the sea breeze is usually around 1,200 to 1,500 ft, but sometimes reaches 3,000 ft or more. Its intensity will vary with the water-land temperature contrast, but usually its speed is 10 to 15 mi/h.

River systems and other deep passes that penetrate the coast ranges provide the principal inland sea breeze flow routes. Lake breezes can appear along the shores of lakes and other bodies of water large enough to establish a sufficient air temperature gradient.

Spurious Winds

Thunderstorm Winds

Thunderstorm winds are (1) the updrafts predominating in and beneath growing cumulus clouds, (2) downdrafts in the latest stages of full thunderstorm development, and (3) cold air outflow from decaying thunderstorm clouds, which sometimes develops squall characteristics. In mountainous terrain, a thunderstorm downdraft tends to continue its downward path into the principal drainageways. Speeds of 20 to 30 mi/h are common and speeds of 60 to 75 mi/h have been measured. The high speeds and surface roughness cause these winds to be extremely gusty. They are stronger when the air mass is hot, as in the late afternoon, than during the night or forenoon. Although they strike suddenly and violently, downdraft winds are of short duration. Downdrafts can also develop on hot days from towering cumulus clouds.

Whirlwinds

Whirlwinds, or dust devils, are one of the most common indications of intense local heating. Such winds occur on hot days over dry terrain when skies are clear and general winds are light. Whirlwinds are common in an area that has just burned over. The blackened ashes and charred materials are good absorbers of heat from the sun, and hot spots remaining in the fire area may also heat the air. A whirlwind sometimes rejuvenates an apparently dead fire, picks up burning embers, and spreads the fire to new fuels. The presence of whirlwinds is a good indicator that conditions are highly unstable and favorable for upslope convective winds.

Nighttime High-Elevation Winds

During the night, winds may reach dangerously high velocities at high-elevation ridgetops. Baughman's (1981) paper about nighttime ridge winds concludes that windspeeds often increase and may reach maximum values on high mountain slopes during the nighttime hours. Evidence, including published information, supports the contention that this weather phenomenon is due to a low-level jet wind.

Interaction Between Winds

Slope and valley wind systems are subject to interruption or modification at any time by the general winds or by larger scale convective wind systems. Midday upslope winds in mountainous topography tend to force weak general winds aloft over the ridgetops. Frequently the daytime upper winds are felt only on the highest peaks. In this situation the surface winds are virtually pure convective winds. Upslope winds dominate the saddles and lower ridges and combine with up-valley winds to determine windspeeds and directions at the lower elevations. A fire burning to a ridgetop under the influence of upslope afternoon winds may flare up and its spread may be strongly affected as it comes under the influence of the general wind flow.

Convective winds (slope, valley, and sea breezes) may be augmented, opposed, or eliminated by general winds. The influence of these general winds on the convective wind systems varies with the strength of the general wind, its direction relative to the convective circulation, and the stability of the lower atmosphere. The interactions between air flow of different origins, local pressure gradients caused by nonuniform heating of mountain slopes, and the exceedingly complex physical shapes of mountain systems combine to prevent the rigid application of rules of thumb to convective winds in mountain areas. Every local situation must be interpreted in terms of its unique qualities. Differences in air heating over mountain slopes, canyon bottoms, valleys, and adjacent plains result in several different related wind systems. These systems combine in most instances and operate together. The common denominator is up-valley, up-canyon, and upslope flow in the daytime, and down flow at night.

Summarizing the wind types of most concern to fire operation, surfacing of strong upper air winds, either frontal or foehn, can usually be considered the most dominant. In the absence of these, valley winds and sea breezes can be expected to dominate, while upslope daytime winds are the most fragile and least dominant. A summary of the expected range of windspeeds from the different wind types is shown in table II-4.

Table II-4.—Windspeed ranges

Wind type	Expected range of windspeed
Frontal winds	Too broad a range to be specific
Foehn	40 to 60 mi/h common; up to 90 mi/h reported at 20 ft
Land breeze	2 to 3 hours after sunset, 3 to 5 mi/h at 20 ft
Pacific sea breeze	10 to 15 mi/h at 20 ft
Up-valley winds	10 to 15 mi/h, early afternoon and evening at 20 ft
Upslope winds	As high as 4 to 8 mi/h at midflame height; see tables II-7, 8, 9
Downslope winds	3 to 6 mi/h at midflame height

WIND ASSESSMENT PROCEDURES

The procedures that follow are designed to provide the detailed assessment of wind at the midflame height necessary to predict fire behavior and growth. In the process of doing so, data will be assembled that can also be used to predict the possibility of severe fire behavior.

The procedures are more detailed than necessary if a fire weather forecaster is available at the fire site. It is hoped, however, that they will facilitate communication with the forecaster so that you will obtain the specific information needed to predict fire behavior.

The procedure progresses step-by-step, serves as a checklist, and can be applied universally. A local checklist should be developed for each section of the country that has unique fire weather patterns. Such a local list could eliminate extraneous material and highlight local problems not addressed in the universal procedure.

The following factors should be considered as you begin your analysis of wind on the fire:

- How much time do you have to complete your assignment and to predict fire behavior?
- Is the prediction to be for daytime or nighttime? Or must you contend with transition between daylight and darkness?
- Is the fire in level or mountainous terrain?
- Is the fire sheltered beneath standing timber or in exposed fuels?
- Are you dealing with the early stage of the fire without control lines or later stages with most control lines complete and secure?
- Are you near a large body of water that can influence windspeed and direction?
- What has the wind done previously?
- Do you have any measured weather data?
- Where can you get your weather information and how soon?

In a wildfire situation you cannot wait until conditions are within prescription as with prescribed fires. You must contend with the situation at hand. Answers to the above questions can dictate in some cases a very rapid assessment of conditions to meet initial requirements. A flow chart outlining the procedures is shown in figure II-5.

Complete procedures are as follows:

STEP 1. CONTACT FIRE WEATHER METEOROLOGIST

Contact the fire weather meteorologist as early as possible to determine the weather expected at the fire site. In some cases this may be done on your way to the fire. Communications may be disrupted, making it difficult to obtain a forecast. You will then have to rely on observations and reports of persons who have observed the weather and its effects during the initial stages of the fire. It will be most helpful to have a forecast for the next 12 to 24 hours in your pocket when you arrive at the fire.

Determine from the fire weather forecaster if general synoptic conditions are likely to change during the next 12 to 24 hours. Even if no general change is expected, surface weather may change due to daily (diurnal) cycles. The important point is that these changes have a very strong tendency to repeat themselves by time of day; in other words, "persist." If a change in the general synoptic conditions is expected due to frontal movements, or other large scale changes, then you cannot rely on persistence forecasting. The diurnal effects due to heating and cooling will still be taking place, but the resulting wind may be quite different due to the rearrangement of the major pressure pattern.

Use the times of expected changes, either due to frontal passages or other synoptic events or due to diurnal changes, to lay out time periods when weather conditions will remain fairly persistent as well as when changes are expected. Use the times of expected stable periods to help identify projection times and note this at the top of the fire behavior worksheets.

STEP 2. CONSIDER POSSIBILITY OF SPURIOUS WINDS

Review the fire weather forecast for information or warnings about weather events that may be accompanied by strong winds. These may include frontal passages with accompanying thunderstorms, surfacing of strong winds aloft, or a wind reversal such as occurs when a general wind counteracts a sea breeze or valley wind. Both valley winds and sea breezes can be reinforced or disrupted by surfacing of the general winds aloft. One such condition, known as a sundowner, often occurs near Santa Barbara, Calif., and causes severe fire problems. Work with your local fire weather forecaster and be prepared to account for interaction between various winds.

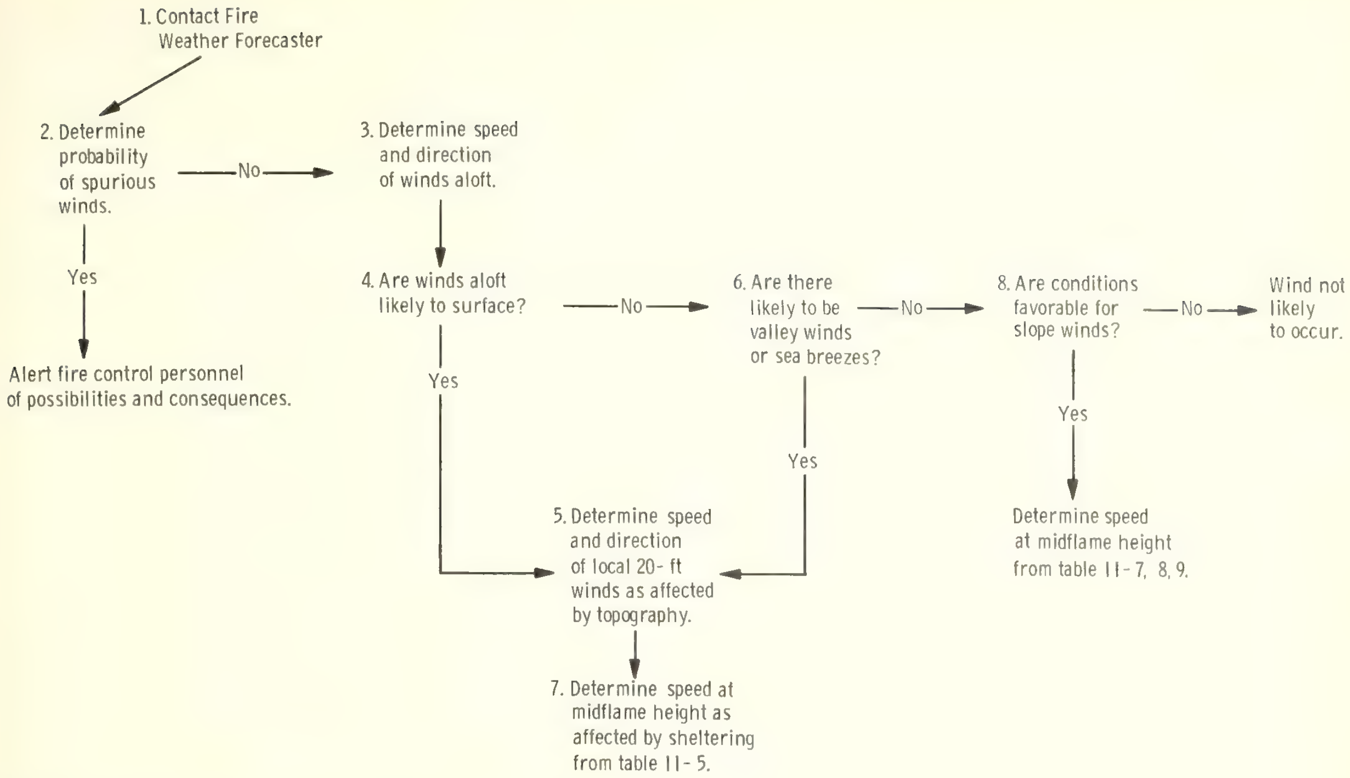


Figure II-5.—Flow chart of wind assessment procedures.

Discuss the weather situation with persons familiar with the local situation. Learn what weather patterns cause problems and the expected time of these events.

Review weather observations. Has there been an occurrence of nighttime high-elevation winds? Is the fire located on the lee side of a ridge, thus making fire whirls a strong possibility?

The occurrence of strong winds for a short time does not lend itself to satisfactory fire growth predictions, but the possible severity of the fire resulting from these winds and the expected time of occurrence should be reported to the fire control forces. Even though accurate predictions of spread cannot be made for spurious winds, an estimate of the fireline intensity and flame length is possible if an estimate of the windspeed is given.

STEP 3. DETERMINE SPEED AND DIRECTION OF THE GENERAL WINDS ALOFT

On a contour map of the fire, place an overlay showing the direction of the general winds aloft, using a few long straight arrows over the fire area. Write the windspeed alongside the arrows. Note the time period on the overlay for which these winds are expected to remain constant (see fig. II-6).

STEP 4. DETERMINE IF WINDS ALOFT ARE LIKELY TO SURFACE

Determine whether or not the general winds aloft are likely to reach the surface. In this instance, the surface is defined as 20 ft above the vegetation. Discuss this with your fire weather meteorologist. If he is not available for discussion, examine the fire weather forecast. If the forecast specifies light upslope winds, then the forecast is essentially saying that the winds aloft will not surface and convective winds will be active. Note the speed of the general winds aloft on the fire weather forecast.

If you do not have a fire weather forecast, but you were able to bring with you or obtain from a general forecast (by radio, television, aviation forecast, or fire lookout observation, or estimate from the movement of low level clouds), the speed and direction of the general winds aloft, you must make your own evaluation of whether these winds will surface. Surfacing of the general winds aloft depends upon several factors:

a. Strength.—Strong winds are more likely to surface than weaker winds aloft.

b. Direction.—Winds aloft that approach the fire area over a long distance, unobstructed by high ridges or mountains, have a better chance of surfacing.

c. Stability.—Very stable air will tend to block or prevent winds aloft from surfacing. Conversely, when mixing is good, the winds are more likely to surface.

Recall from Schroeder and Buck (1970) that the general winds can be held aloft by mountain ridges, by strong convective upflow, or by very stable air resulting from a strong inversion. Ryan (1977) indicates that unless the general winds aloft are sufficiently strong (he estimates the limit to be at least 13 mi/h at the 5,000-ft level), they will have little effect at the surface. If the general winds are not expected to reach the surface, proceed to step 6 and determine if convective winds can be expected. If the winds aloft are expected to surface, determine the expected speed and direction as explained in step 5.

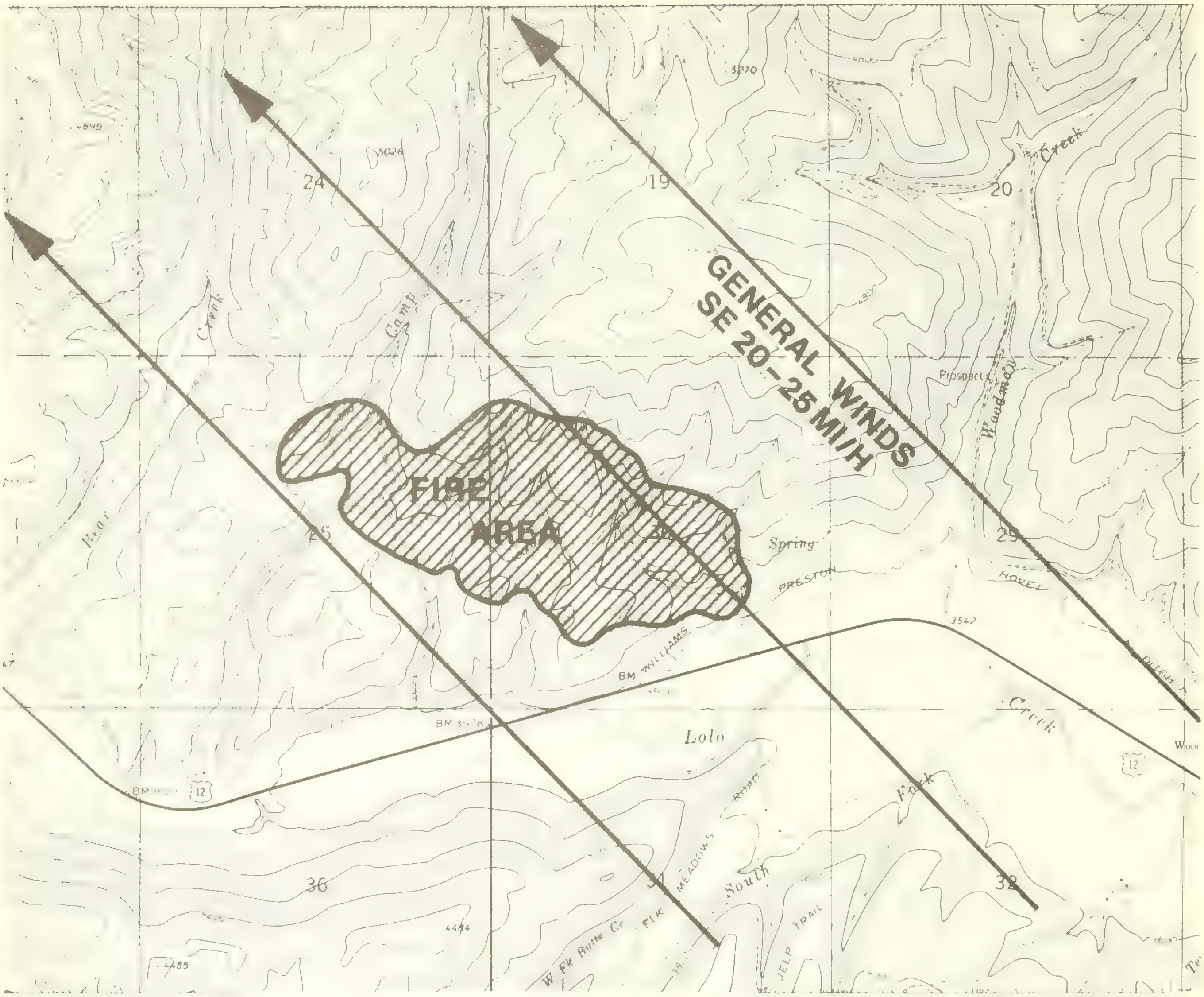


Figure II-6.—Diagrammatic layout of general winds aloft.

STEP 5. DETERMINE THE SPEED AND DIRECTION OF THE LOCAL 20-FT WINDS

Place the wind overlay upon a topographic map of the fire area. Study the topography, taking into account the mountains, ridges, valleys, and exposed slopes. Mentally, bring the general wind aloft down toward the surface. The general wind can be pictured to move as a blanket of air over terrain features or around them, but generally moving in the same direction after a barrier is passed. Consider air as a fluid that can flow just as water could flow over or around a rock in a stream. Adjust its direction and velocity to fit the terrain. Look upwind of the fire area. How far can the wind travel without terrain obstructions before it reaches the fire? If the distance is long, across a major valley or large lake, the wind will sweep into the fire area with little restraint and have speeds only slightly less than the general wind. If the unobstructed approach distance is short because of terrain blockage, then the wind will be slowed considerably. In such cases ridgetop winds may be high, but the valley winds will be low. Estimate intermediate speeds on the slopes. The important consideration is the effect of the terrain and not the sheltering effect of the trees. On the overlay draw arrows that represent your best estimate of the direction of the resulting 20-ft wind (fig. II–7). Beside the arrow write the estimated windspeed. Use a range of windspeeds, if you prefer, such as 5 to 8 mi/h. As you become proficient at this you will note that it is natural to draw longer arrows for the positions where stronger winds are expected such as across ridgetops, and shorter arrows where terrain features will block or slow the flow. Do not attempt an exact scale of the lengths, but keep them relatively consistent.

While drawing the arrows, be concerned with both direction and speed. Use the topography information on the map to decide whether it would be easier for the wind to go up a slope and over the top or to change direction and flow around an obstructing terrain feature and up a nearby valley. On the lee side of ridges look for a flow reversal where the wind changes direction and flows back up the ridge. This is an area where highly variable winds can develop.

In most fire situations, the fire behavior officer will obtain wind information from as many locations around the fire as possible, such as from fire lookout towers, from an anemometer set up near the fire camp, and from observers on ridges,

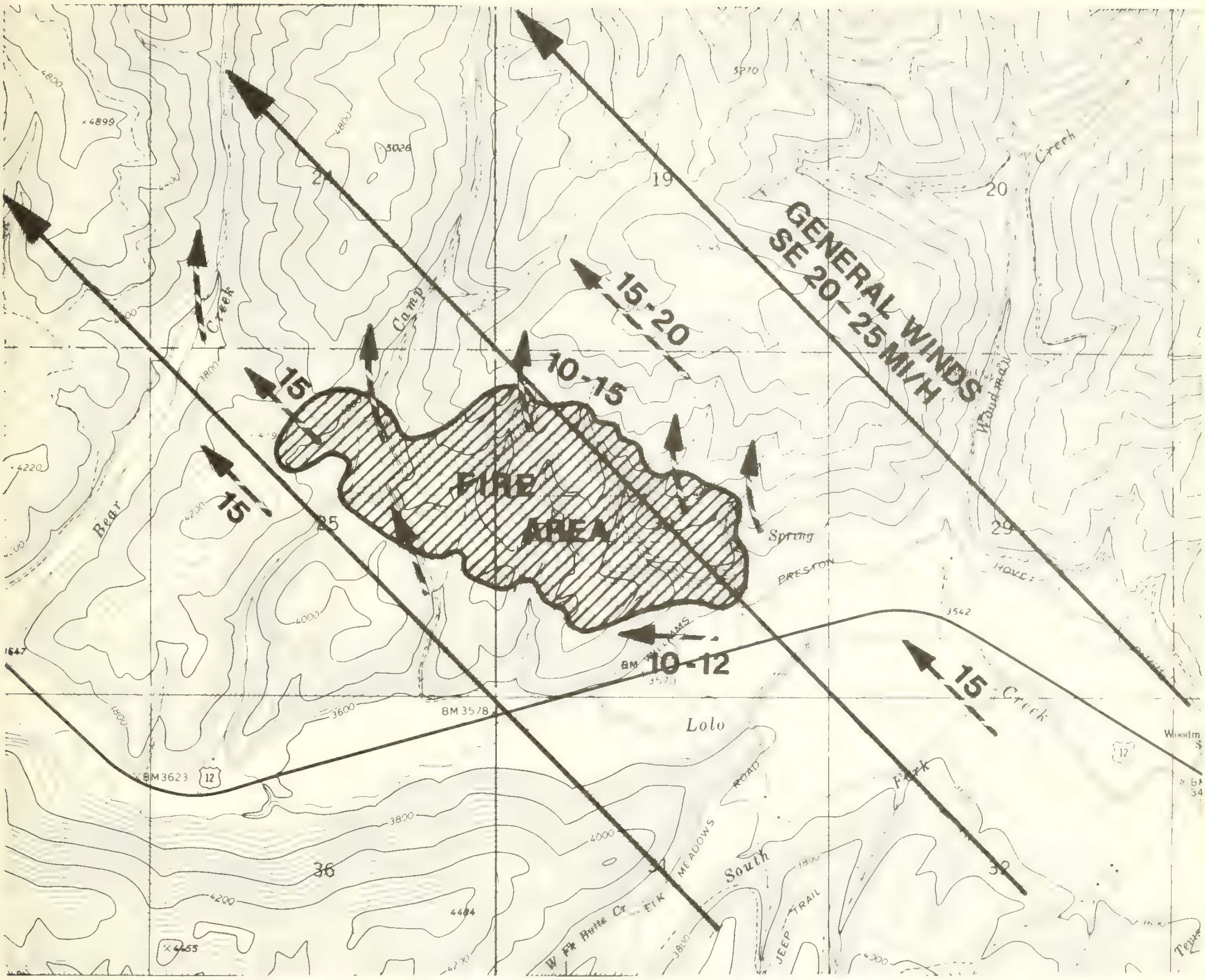


Figure II-7.—Diagrammatic layout of local winds as influenced by topography.

on the fireline, and other significant locations around the fire area. Initial estimates of windspeed and direction are the most difficult. After a day or two on a fire, recognizable wind patterns tend to develop, and interpretations of windspeed and direction can be made at intermediate points between the lookouts at the top of mountains and the observation points in valley bottoms.

Chapter IV will discuss how to locate projection points at strategic locations around the fire. Be sure you have drawn an arrow representing the direction of the 20-ft wind, and an estimate of its speed near all projection points. Enter the value of the 20-ft windspeed at each projection point on line 11 of the fire behavior worksheet. Use separate columns for each projection point.

STEP 6. DETERMINE THE PROBABILITY OF VALLEY WINDS OR SEA BREEZES

If the general winds aloft are not expected to surface at the fire site at the time for which you are predicting wind, determine if valley winds or sea breezes are likely to develop.

Whether or not valley winds will occur or whether there will be slope winds without valley winds depends not only on the heating and resulting convective flow as discussed earlier, but also on the direction of the general winds aloft and stability of the valley air. If a nighttime inversion has filled the valley, the valley winds will not begin until the inversion has been broken. Upslope flow will begin well before up-valley flow when inversions are present in the morning. When the inversion has been broken, exposure of the valley to the flow of the general winds aloft is a primary consideration regarding the expected onset of valley winds.[8]

On the overlay show the direction of the wind flow, taking into account the general layout of the valley systems as shown in Schroeder and Buck (1970). The speed will be highest in the major valleys, 10 to 15 mi/h at the 20-ft level.

[8]Personal communication with Clyde O'Dell and Frank Gift, U.S. Weather Service fire meteorologists at the Boise Interagency Fire Center.

If the fire is located near a coastline, land and sea breezes must be considered. The daily land and sea breezes tend to occur quite regularly when there is no significant influence from the general wind flow. When general winds are sufficiently strong, however, they usually mask the land and sea breezes. A general wind blowing toward the sea opposes the sea breeze and, if strong enough, may prevent its development.

The speed of sea breezes may reach 10 to 15 mi/h at the 20-ft level under favorable conditions and extend inland 30 to 40 miles. When blocked by mountains, they tend to follow major river drainages.

The land breeze begins 2 to 3 hours after sunset, and ends shortly after sunrise. It is a more gentle flow than the sea breeze, usually about 3 to 5 miles per hour. The land air, having been cooled from below by contact with the ground, is stable. The land breeze, therefore, is more laminar and shallower than the sea breeze.

Draw arrows representing the 20-ft valley winds, land breezes, and sea breezes on the overlay near the fire area just as was done for general winds that surface. Note the probable speed on the arrows. Enter the value of the 20-ft windspeed for each projection point on line 11 of the fire behavior worksheet.

STEP 7. ESTIMATE MIDFLAME WINDSPEED

Steps 5 and 6 produced estimates of the wind at 20 ft above the vegetation. Because wind is slower near the surface, fires with flame heights less than 40 ft must have the wind adjusted to the midflame height. This is done with a wind adjustment table developed from the research of Albini and Baughman (1979).

Table II–5 is designed for quick field reference. Given an estimate of the 20-ft windspeed from steps 5 or 6 and the sheltering conditions near the fire, an estimate of the midflame windspeed can be read directly from the table. The 20-ft windspeed ranges at the head of the columns are the same as used in table II–3, thus facilitating the conversion of windspeed observations based on the Beaufort scale.

Table II–6 displays the adjustment factors used to develop table II–5. If more time is available for making predictions and you wish to avoid the step changes in windspeed and ultimately in rate of spread that table II–5 will produce, then use the wind adjustment factor given in table II–6. Midflame windspeed is obtained by multiplying the 20-ft windspeed by the wind adjustment factor.

Table II-5.— Wind adjustment table—quick reference. Values shown are approximate midflame windspeeds (mi/h) for range of 20 ft windspeed shown at top of column.

Fuel exposure	Fuel model		20-ft windspeed (mi/h) 0–3	4–7	8–12	13–18	19–24	25–31	32–38	39 up
			Midflame windspeed (mi/h)							
EXPOSED FUELS										
Fuel exposed directly to the wind—no overstory or sparse overstory; fuel beneath timber that has lost its foliage; fuel beneath timber near clearings or clearcuts; fuel on high ridges where trees offer little shelter from wind	4		1	3	6	9	13	17	21	24
	13		1	3	5	8	11	14	18	20
	1,3,5,6,11,12 (2,7)[1] (8,9,10)[2]		1	2	4	6	9	11	14	16
PARTIALLY SHELTERED FUELS										
Fuel beneath patchy timber where it is not well sheltered; fuel beneath stands of timber at midslope or higher on a mountain with wind blowing directly at the slope	All fuel models		1	2	3	5	7	8	11	12
FULLY SHELTERED FUELS										
Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes	All fuel models	Open stands	0	1	2	3	4	6	7	8
		Dense stands	0	1	1	2	2	3	4	4

[1]These fuels are usually partially sheltered.

[2]These fuels are usually fully sheltered.

Table II-6.— Wind adjustment table. Find the appropriate adjustment factor and multiply it by the 20-ft windspeed. Use the result as the midflame windspeed

Fuel exposure	Fuel model	Adjustment factor
EXPOSED FUELS		
Fuel exposed directly to the wind—no overstory or sparse overstory;	4	0.6
fuel beneath timber that has lost its foliage; fuel beneath timber near clearings or clearcuts; fuel	13	0.5
on high ridges where trees offer little shelter from wind	1,3,5,6,11,12 (2,7)[1] (8,9,10)[2]	0.4
PARTIALLY SHELTERED FUELS		
Fuel beneath patchy timber where it is not well sheltered; fuel beneath standing timber at midslope or higher on a mountain with wind blowing directly at the slop	All fuel models	0.3
FULLY SHELTERED FUELS		
Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes	All fuel models: Open stands	0.2
	All fuel models: Dense stands	0.1

[1]Fuels usually partially sheltered.
[2]Fuels usually fully sheltered.

The wind adjustment tables contain three sections to account for various sheltering of fuels from wind. These are illustrated in figure II–8.

1. *Exposed fuels.*—The upper section of the wind adjustment tables is used for fuels that are fully exposed (no shelter) to the wind, with no overstory or only scattered trees.

The upper section should also be used for trees that have lost their foliage such as hardwoods in the fall or early spring. Trees that have been defoliated by crown fire or insects expose surface fuels to stronger winds and the upper portion of the table should be used.

The upper section should also be used for fuels that are beneath timber, but near the edge of a clearing. Shade-intolerant trees such as lodgepole or ponderosa pine can have wind penetration an equivalent of 10 tree heights[9] from the edge before it is slowed to the fully sheltered condition. Because of their growth forms, shade-tolerant trees offer more resistance, and the wind will be slowed in five tree heights.[9] Of course the clearing has to be large enough for the wind to build up its speed before hitting the timber edge. The size of the clearing and the penetration distance cannot be specified at this time and experience must be your guide. Clearings for this situation can be natural or manmade, such as clearcuts from logging, lakes, burned-out trees resulting from crown fires, etc.

Fuels on high ridges where trees offer little shelter from wind should also use the upper portion of the chart.

Fuel models not normally found in fully exposed conditions are indicated by footnotes

2. *Partially sheltered fuels.*—The middle section of the wind adjustment tables is used for partially sheltered fuels. This would include fuel beneath patchy timber or timber that is scattered. Fuel model 2, a grass model, is more often found as a partially sheltered fuel than as a fully exposed fuel. Fuel model 7, when used to represent southern rough, may be partially sheltered.

A mountainside directly exposed to a strong general wind is more likely to have only partially sheltered fuels even though covered with timber. This would be more likely on mid- and upper slopes than on lower slopes.

3. *Fully sheltered fuels.*—The lower portion of the table is used for fully sheltered fuels. Sheltered fuels are found within timber stands. Sheltering can be more or less restrictive, depending on the characteristics of the overstory. Trees that have branches extending all the way to the ground, such as spruce and cedar, can be very restrictive to airflow. These trees are broadly classified as shade-tolerant trees. Shade-intolerant trees typically have less dense crowns and so are less restrictive to windflow. Their conformation tends to be more open, and when growing close together the lower branches defoliate. Pines are typically intolerant, while firs are shade tolerant. Either type can be found in open or in dense stands; a correction factor is provided in the table. Trees and stocking configurations vary so widely that precise instructions cannot be given for all situations. Experience must play a large part in learning to choose the best wind adjustment value.

Enter the value of the wind adjustment factor on line 12 of the fire behavior worksheet. Multiply it by the 20-ft windspeed on line 11 to obtain the midflame windspeed, which is entered on line 13. This should be done in a separate column for the wind conditions at each projection point.

STEP 8. DETERMINE SLOPE WINDS

Upslope winds.—If the general winds are not expected to surface and the fire is not subject to major valley winds or sea breezes, there is still the distinct possibility of slope winds developing that will affect surface fires on mountain slopes. Nighttime downslope winds can almost be guaranteed; however, daytime upslope winds are more uncertain. If the sun is reaching slopes that are not timber covered and there is no disturbance by other winds, upslope winds will develop. Most fire weather forecasts will contain an estimate of their velocity. Slope winds should be forecast at eye level because they cannot be reduced from the 20-ft level by the same procedures used for the deep winds; i.e., general, valley, and sea breezes. If you do not have an eye-level forecast, or you wish to check the value, this can be done with the procedures of Albini and others (1982), which follow.

Midflame windspeeds were developed for 10 of the NFFL stylized fuel models that might be used for predicting fire behavior on open slopes. Fuel models 7, 8, and 9 were not included because they are used only for fuels under standing timber. Model 10 is also an understory fuel, but is sometimes used to represent logging slash overgrown with shrubs, grasses, and forbs, and so it was included. Tree cover on the slope both interferes with the solar heating of the surface and obstructs the development of the convective wind field, so the model cannot be used for tree-covered slopes.

[9]Baughman, Robert G. Wind at the forest edge. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Forest Fire Laboratory; 1980. Unpublished report.

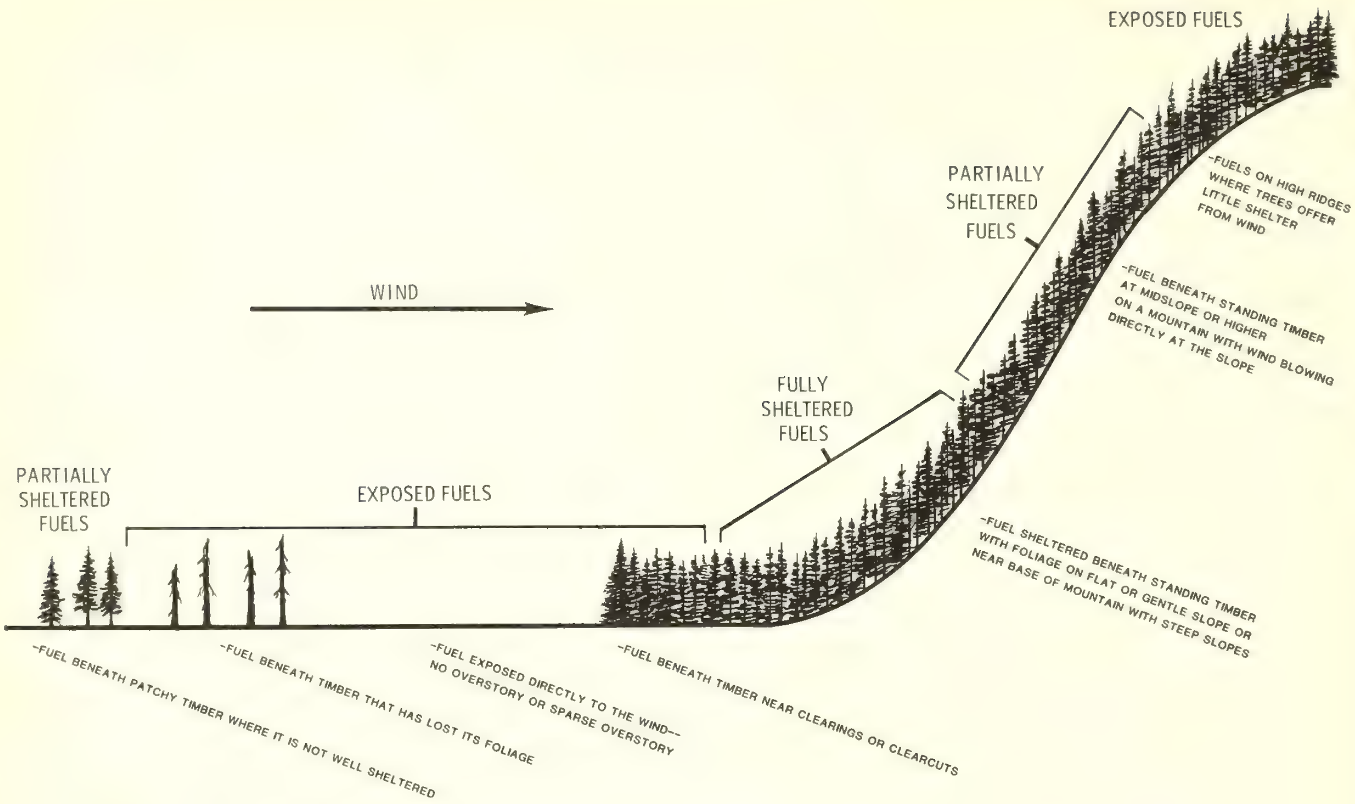


Figure II-8.—Exposure of various fuels to wind.

Two situations are considered:

1. The slope is uniformly covered with the fuel below the fire site, and
2. The slope below the fire site is free of cover.

The first situation might represent a prescribed fire, a new ignition on a slope, or a wildfire backing downslope. The second situation might represent a slope with a rock or scree face, or a fire burning upslope from near the base in which the fuel has burned out behind the fire.

The fuel models used can be divided into "shallow" and "deep" fuelbeds. The "shallow" fuelbeds are represented by models 1, 2, 5, 6, 10, and 11. Midflame windspeeds for these models are a function of slope only. Table II-7 gives midflame windspeeds for these models.

The "deep" fuelbeds, represented by stylized models 3, 4, 12, and 13, exhibit some degree of dependence of midflame windspeed on both slope and elevation above the valley floor. Table II-8 gives the midflame windspeeds for these models for the case of uniform cover below the fire site. For the case of a bare slope below the fire site, use table II-9.

Table II-7.— Midflame windspeeds (mi/h) for "shallow" fuelbeds with upslope convection winds

	Slope (percent)								
Fuel model	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
A. Slope uniformly covered with vegetation below fire site									
Fuel model									
1. Short grass	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.9	0.9
2. Timber (grass and understory)	.4	.5	.7	.8	.9	1.0	1.1	1.2	1.3
5. Brush	.3	.5	.6	.7	.8	.9	1.0	1.1	1.2
6. Dormant brush, hardwood slash	.5	.7	.9	1.0	1.2	1.3	1.4	1.5	1.6
10. Overgrown slash[1]	.4	.5	.7	.8	.9	1.0	1.1	1.2	1.3
11. Light conifer slash	.3	.4	.5	.6	.7	.8	.9	.9	1.0
B. Slope below fire site free of vegetation cover									
Fuel model									
1. Short grass	0.5	0.8	1.0	1.2	1.4	1.5	1.6	1.8	1.9
2. Timber (grass and understory)	.6	.9	1.2	1.4	1.6	1.8	1.9	2.1	2.2
5. Brush	.9	1.3	1.6	1.9	2.2	2.4	2.6	2.8	2.9
6. Dormant brush, hardwood slash	1.1	1.6	2.1	2.5	2.8	3.1	3.3	3.5	3.7
10. Overgrown slash[1]	.6	.9	1.2	1.4	1.6	1.8	1.9	2.1	2.2
11. Light conifer slash	.6	.8	1.0	1.2	1.4	1.6	1.7	1.8	1.9

[1]Normally called timber litter and understory.

Table II-8.— Midflame windspeeds (mi/h) for "deep" fuelbeds with upslope convection winds. Slope uniformly covered with vegetation below fire site

Fuel model	Slope (percent)								
	20	30	40	50	60	70	80	90	100
FUEL MODEL 3 – Tall Grass									
Ht. above valley floor									
0-300 ft	0.7	1.0	1.2	1.5	1.7	1.9	2.0	2.1	2.2
300-600	.7	1.0	1.3	1.5	1.7	1.9	2.0	2.2	2.3
600-900	.7	1.0	1.3	1.5	1.7	1.9	2.1	2.2	2.3
900-1200	.7	1.0	1.3	1.5	1.7	1.9	2.1	2.2	2.3
1200-1500	.7	1.0	1.3	1.5	1.7	1.9	2.1	2.2	2.3
FUEL MODEL 4 – Chaparral									
Ht. above valley floor									
0-300 ft	1.3	1.9	2.3	2.7	3.0	3.3	3.5	3.7	3.9
300-600	1.3	1.9	2.4	2.8	3.1	3.4	3.7	3.9	4.0
600-900	1.3	1.9	2.4	2.8	3.2	3.5	3.8	4.0	4.2
900-1200	1.3	1.9	2.4	2.9	3.2	3.6	3.8	4.1	4.3
1200-1500	1.3	1.9	2.4	2.9	3.3	3.6	3.9	4.1	4.3
FUEL MODEL 12 – Medium Conifer Slash									
Ht. above valley floor									
0-300 ft	0.7	1.0	1.2	1.4	1.6	1.8	2.0	2.1	2.2
300-600	.7	1.0	1.2	1.5	1.7	1.8	2.0	2.1	2.2
600-900	.7	1.0	1.2	1.5	1.7	1.9	2.0	2.1	2.3
900-1200	.7	1.0	1.2	1.5	1.7	1.9	2.0	2.2	2.3
1200-1500	.7	1.0	1.3	1.5	1.7	1.9	2.0	2.2	2.3
FUEL MODEL 13 – Heavy Conifer Slash									
Ht. above valley floor									
0-300 ft	0.9	1.3	1.6	1.9	2.1	2.4	2.5	2.7	2.8
300-600	.9	1.3	1.6	1.9	2.2	2.4	2.6	2.7	2.9
600-900	.9	1.3	1.6	2.0	2.2	2.4	2.6	2.8	2.9
900-1200	.9	1.3	1.7	2.0	2.2	2.5	2.7	2.8	3.0
1200-1500	.9	1.3	1.7	2.0	2.3	2.5	2.7	2.9	3.0

Table II-9.— Midflame windspeeds (mi/h) for "deep" fuelbeds with upslope convection winds. Slope bare of vegetation below fire site

Fuel model	Slope (percent)								
	20	30	40	50	60	70	80	90	100
FUEL MODEL 3 – Tall Grass									
Ht. above valley floor									
0-300 ft	1.3	1.9	2.4	2.8	3.1	3.4	3.6	3.8	4.0
300-600	1.3	1.9	2.4	2.8	3.2	3.5	3.7	4.0	4.1
600-900	1.3	1.9	2.4	2.9	3.2	3.6	3.8	4.1	4.2
900-1200	1.4	1.9	2.5	2.9	3.3	3.6	3.9	4.1	4.3
1200-1500	1.4	2.0	2.5	2.9	3.3	3.7	4.0	4.2	4.4
FUEL MODEL 4 – Chaparral									
Ht. above valley floor									
0-300 ft	2.7	3.7	4.4	5.0	5.5	5.8	6.1	6.3	6.5
300-600	2.7	3.8	4.6	5.3	5.8	6.2	6.6	6.8	7.0
600-900	2.8	3.9	4.8	5.5	6.1	6.5	6.9	7.2	7.5
900-1200	2.8	3.9	4.9	5.7	6.3	6.8	7.2	7.5	7.8
1200-1500	2.8	4.0	5.0	5.8	6.5	7.0	7.4	7.8	8.1
FUEL MODEL 12 – Medium Conifer Slash									
Ht. above valley floor									
0-300 ft	1.3	1.8	2.2	2.6	3.0	3.2	3.5	3.7	3.8
300-600	1.3	1.8	2.3	2.7	3.0	3.3	3.6	3.8	4.0
600-900	1.3	1.8	2.3	2.7	3.1	3.4	3.7	3.9	4.1
900-1200	1.3	1.8	2.3	2.8	3.1	3.5	3.7	3.9	4.1
1200-1500	1.3	1.9	2.4	2.8	3.2	3.5	3.8	4.0	4.2
FUEL MODEL 13 – Heavy Conifer Slash									
Ht. above valley floor									
0-300 ft	1.6	2.3	2.9	3.3	3.7	4.0	4.3	4.5	4.7
300-600	1.7	2.3	2.9	3.4	3.8	4.2	4.5	4.7	4.9
600-900	1.7	2.4	3.0	3.5	3.9	4.3	4.6	4.9	5.1
900-1200	1.7	2.4	3.0	3.6	4.0	4.4	4.7	5.0	5.2
1200-1500	1.7	2.4	3.1	3.6	4.1	4.5	4.8	5.1	5.3

Downslope winds.—Downslope winds begin to form as soon as shadows form on the slopes. This time can be very late in the day during the middle of the summer in northern latitudes. The depth of the downslope winds rarely exceeds 8 to 10 ft above the ground and they are often much less. They tend to be deeper near the bottom of slopes compared to the upper slope. Their speed can be as high as 3 to 6 mi/h, and occasionally higher near the base of the slope. The speed of the downslope wind should be considered the midflame wind. Downslope winds can flow beneath the timber canopy, whereas upslope winds usually do not.

Enter the midflame windspeed for slope winds on line 13 of the fire behavior worksheet.

Example 1. Refer to figure II-9.

The LaValle Creek Valley opens onto a large flat plain to the south and west of DeSmet. The vegetation in the area shown on the map is sparse grass about 1 ft in height from the valley floor up to 4,000 ft elevation. Above 4,000 ft it is scattered ponderosa pine on the south- and west-facing slopes and Douglas-fir on the north- and east-facing slopes. The highest peaks in this area are 6,500 ft and located to the north about 2 miles.

Assume a cloudy day with general winds from the southwest at 20 to 25 mi/h.

a. Indicate the speed and direction of the general winds on a map overlay.

b. A 20-ft anemometer at point A is indicating southwest winds at 8 to 10 mi/h. Indicate the speed and direction of the 20-ft wind at points B, C, D, E, F.

c. Estimate the midflame windspeed at points B, C, D, E, F, where fuel model 1 applies to grass-covered slopes, fuel model 9 to scattered ponderosa pine slopes, and fuel model 8 to closed canopy Douglas-fir stands.

Solutions to parts a and b are shown on figure II-10.

Solution to part c:

Point	20-ft wind	Fuel model	Wind adjustment factor	Midflame wind
B	6.5	1	0.4	3
C	6.5	1	.4	3
D	17.5	1	.4	7
E	15	8	.2	3
F	15	9	.3	5

Explanation of Solution

1b. At points B and C, the wind will follow the contours of these narrow valleys. It will be slowed somewhat by the increased resistance to flow over what it was at point A. Although the air will be funneled through the valley, I would not expect the velocity to increase because of the ever-increasing slope beyond these points.

Point D is exposed on a knob that will experience unobstructed flow. The direction should be from the southwest and the velocity greater than in the valley at A, but not as high as the general winds because the knob is only 4,025 ft while 6,000-ft mountains are just behind it.

Point E is located on the lee side of a ridge that will cause a sharp change of direction in the general wind flow. The airflow can come around from the left or roll over the top. The results will be a turbulent eddy. The speed can be high, but will have larger fluctuations than at other points.

Point F is in a gully on a windward facing slope. The wind direction will follow the gully. The speed will be higher than at B and C, but somewhat less than at D.

1c. You were encouraged to use a range in wind velocities when estimating 20-ft winds, both to realize that there will be fluctuations and to erase the notion that you had to have the precise windspeed. The fire spread model, however, can only accept one windspeed at a time; therefore, to expedite a solution, use the midrange value of your estimate and realize that the calculated rate of spread will also be in the form of a range. When you have time you may want to make a calculation with both ends of the wind range estimate to see the range of uncertainty that can be expected due to wind variation. The midrange values for each 20-ft windspeed were used in the solution and shown in tabular results.

Decimals are used to show how the problems are solved and give resolutions to the answers. Do not expect to be able to predict wind this accurately.

Fuel models are selected from the information given. Point D is barely over 4,000 ft and grass was assumed to persist over the knob.

Wind adjustment factors were taken from table II-6.

At point E it is assumed that a sparse, closed-canopy Douglas-fir stand is on the north side of this ridge. The wind does not blow directly at this stand of trees.

At point F the canopy is sparse and it is on a windward-facing slope, so the surface fuel is only partially sheltered. The midflame wind is found by multiplying the wind adjustment factor at each point by the 20-ft wind at that point.

Example 2

The general wind is calm. It is a clear day. The temperature in the valley is 85° F and relative humidity is 18 percent. Air in the valley is generally calm. An occasional dust devil is formed in the valley and on the slopes. It is 1300 hours on July 1.

a. What is the expected windspeed and wind direction at points G and H on figure II-9? The slope at point G is 33 percent and at point H it is 14 percent.

b. What would be the midflame windspeed at point G if the slope were uniformly covered with 6-ft-deep chaparral brush?

c. If the chaparral were burned away below point G, what would be the midflame windspeed at that point?

d. At night, what speed and direction would you expect the wind to be at point G?

Solution

2a. For the conditions described, upslope convective winds are the most probable type of wind.

The slopes are grass-covered, both above and below the site.

From table II-7A for fuel model 1 on a 33 percent slope, the midflame windspeed would be 0.4 mi/h.

The slope at point H is only 14 percent, so the midflame wind as indicated by table II-7A will be less than 0.3 mi/h.

2b. Fuel model 4 is 6 ft deep. For deep fuelbeds, the elevation height above the valley floor is needed. Point G is about 300 ft above the valley floor. From table II-8, the midflame windspeed would be 1.9 mi/h.

2c. From table II-9, the midflame windspeed would be 3.7 mi/h.

2d. Downslope winds on this small foothill would probably not be very much—certainly less than the 3 to 5 mi/h quoted in the text. Point G is subject, however, to down-valley winds after transition to down-valley flow begins in the early evening. For this small valley, down-valley wind would probably be on the order of 3 to 5 mi/h at the 20-ft level.

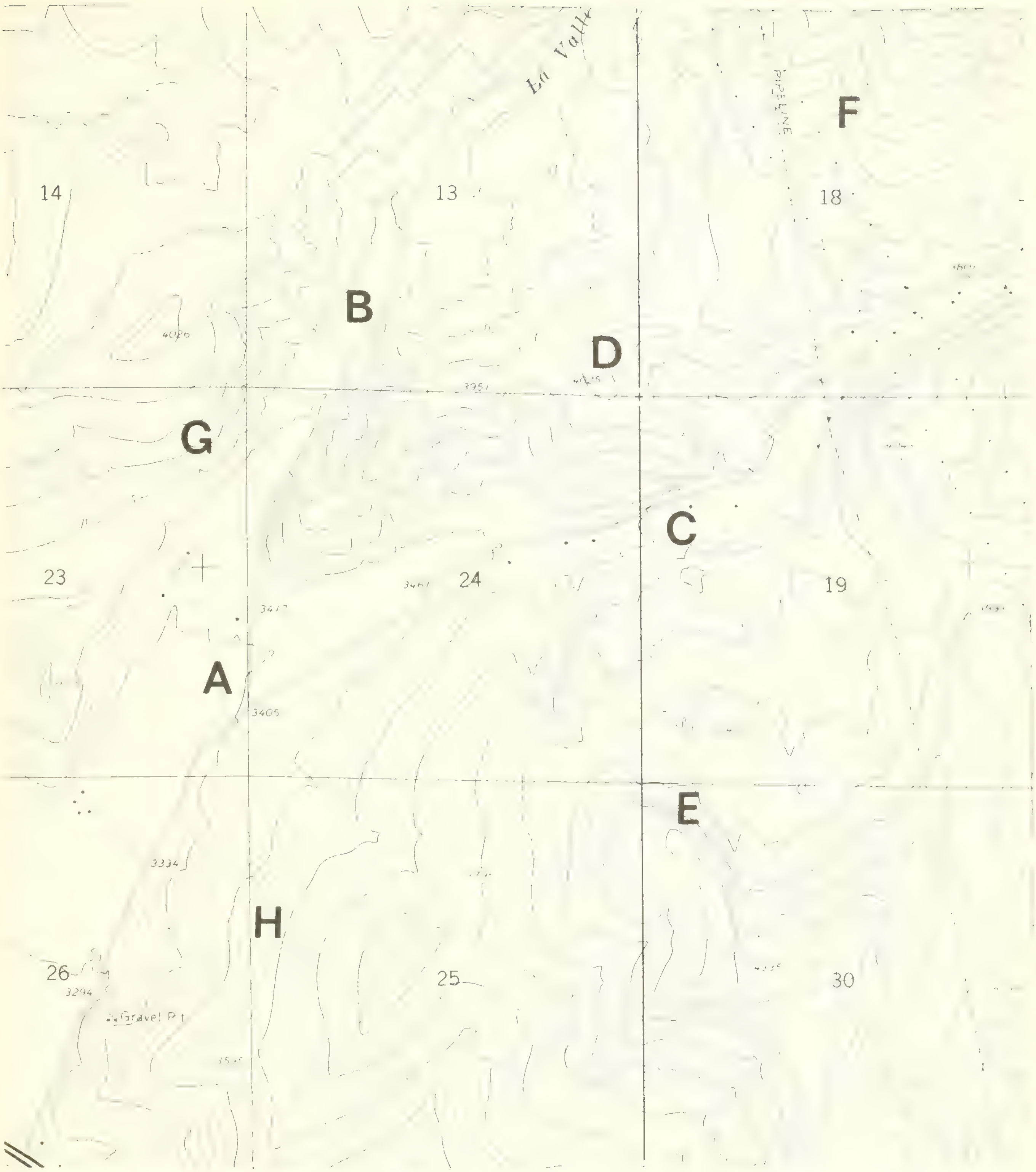


Figure II-9.—Map of LaValle Creek for wind examples.

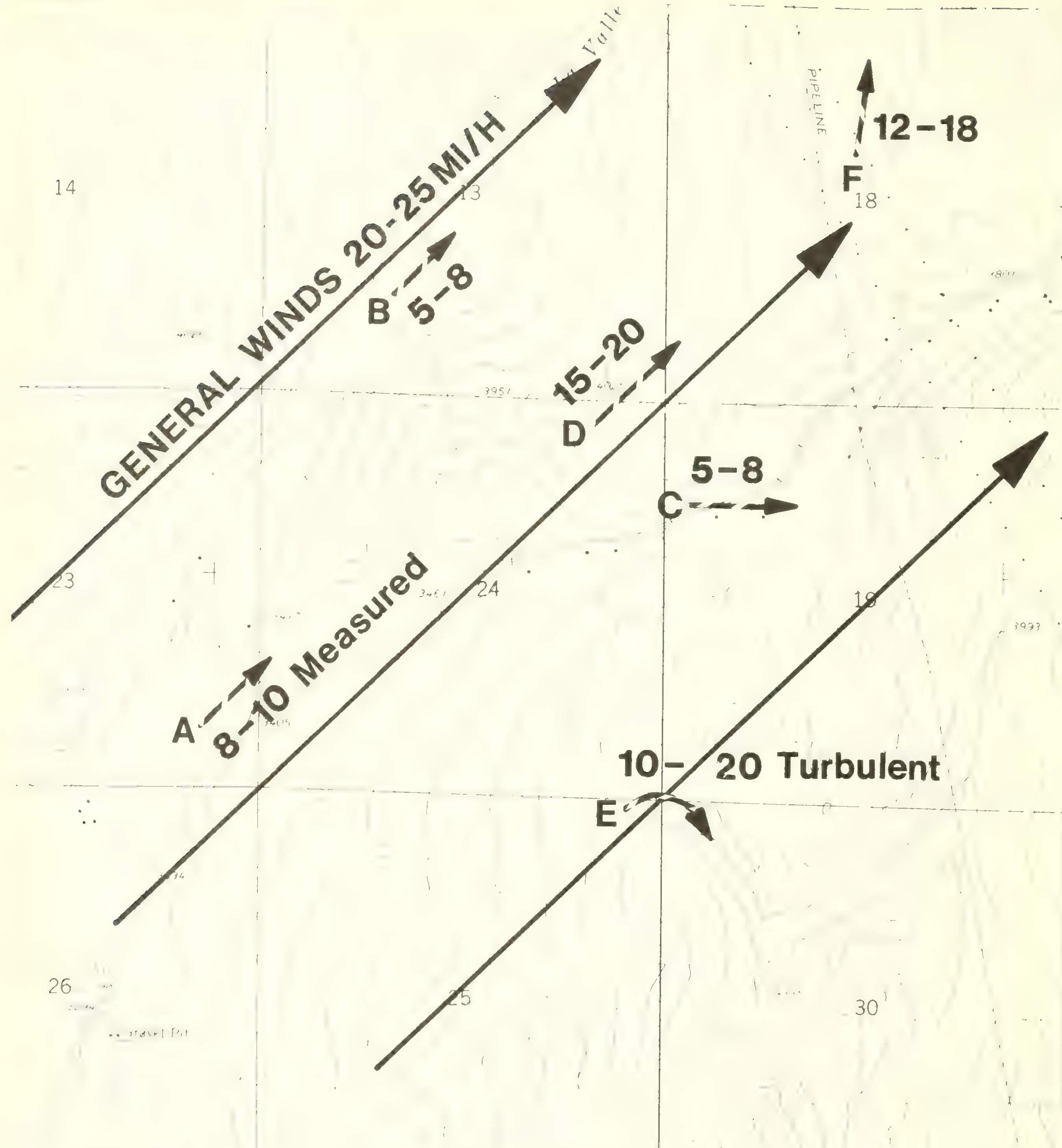


Figure II-10.—Solution to wind exercise 1 shown on map of LaValle Creek.

Slope

Fire can spread significantly faster up a slope than on level terrain in the same fuels. Flame length will also be greater on a slope. The fire model uses positive slope much as it uses wind to adjust rate of spread and flame length. The input used by the model to account for slope is the maximum percent slope of the terrain above the fire. The fire model does not account for negative slopes and will not accept negative values. If you are concerned with a fire backing down a slope, an approximate rate of spread may be calculated by using zero slope as the input. Cases where the wind is driving the fire downslope or cross-slope are discussed in chapter IV, under "Line Fire."

The objective of this section is to illustrate how to determine percent slope as needed for predicting fire behavior.

Both wind and slope tilt the flame over the unburned fuel and bring it to ignition temperature sooner than if they were not present. This causes faster spread rates and longer flame lengths. Slope is particularly important at low windspeeds. At higher windspeeds the wind can dominate the fire so that the effect of slope is not as apparent. Slope is much easier to assess than wind because the latter is so changeable. Slope can be frustrating, however, in rough terrain. Learn to disregard small undulations with respect to the size of the fire or that the fire may cross in a time that is short compared to the observed run time. The shorter the time for preparing your prediction, the less precise you can be on slope determination and accounting for its variation.

It is necessary to be able to make slope determinations from observations on-site or from a topographic map.

DETERMINING SLOPE ON-SITE

In many situations, an estimation of slope is sufficiently accurate. A better method is to measure the slope with an instrument such as a clinometer. Slopes steeper than 100 percent do not normally support vegetation. Slopes usually look much steeper when viewed from the top down than from the bottom up. Slopes can often be judged more accurately from a distance. As you drive to a fire, note the angles of the terrain against the skyline. Do the same thing on-site. Turn 90 degrees and look at the end of the valley to see the slope as a line. If you are on a uniform section that is representative of the general slope, rest one end of a 4- to 6-ft stick on the slope and hold the other end so the stick is as horizontal as possible. The slope can then be estimated from the angle where it rests on the ground or as the ratio of height of the stick from the ground to the length of the stick. Although this sounds crude, it is about the accuracy needed, and the accuracy you can expect to achieve when estimating other variables.

TOPOGRAPHIC MAPS

In many situations, even in the field, you will be working with topographic maps or maps with elevation contours. There are a great many methods, tables, and shortcuts for determining slope from a contour map. If you have a favorite one and it works well, use it. Only the direct calculation method will be discussed here.

The slope between two points is simply the change in elevation between two points divided by the horizontal distance between them. This ratio multiplied by 100 gives the slope in percent.

The process can be summarized in five steps:

1. Determine the contour interval. This is the elevation change between adjacent contour lines.

   Example: 40 ft

2. Determine the map scale and conversion factor. The map scale must be found in terms of the number of feet that each inch on the map represents (ft/in).

   a. Map scales are usually given as the number of inches per mile, such as 2 inches/mi, or as a representative fraction such as 1:31,680. Use table II–10 to convert these map scales to feet per inch.

Table II-10.— Conversion factors for map scale

Representative fraction	Inches/mile	Feet/inch
1:253,440	1/4	21,120
1:126,720	1/2	10,560
1:63,360	1	5,280
1:31,680	2	2,640
1:24,000	2-5/8 (2.64)	2,000
1:21,120	3	1,760
1:15,840	4	1,320
1:7,920	8	660

Example: 2 inches/mi = 2,640 ft/inch
and
1:31680 = 2,640 ft/inch

   b. If table II–10 is not available, use the spacing of section lines to determine the map scale. Normally section line spacing is 1 mile; be careful of foreshortened sections; look around on the map and find square sections with equal spacing. Measure the distance with a ruler graduated in inches and tenths of inches. Divide 5,280 by the map distance between section lines.

   Example: Measured map distance is 2.64 inches

$$\text{Map scale} = \frac{5,280}{2.64} = 2,000 \text{ ft/inch}$$

3. Determine rise in elevation by counting contour intervals and convert to feet.

   Example: 11 contour intervals at 40 ft per interval equals 440 ft.

4. Measure the horizontal distance with a ruler graduated in inches and tenths of inches, and convert to feet with the map scale from step 2.

   Example: 1.2 inches × 2,640 ft/inch equals 3,168 ft.

5. Divide the rise in elevation from step 3 by the horizontal distance from step 4.

$$\text{Example: } \frac{440}{3,168} \times 100 = 14\%$$

When slope is determined, enter it on line 14 of the fire behavior worksheet.

SLOPE EXAMPLES

Samples: When using the contour map that follows, calculate the slope between the following pairs of points:

A and B
C and D
E and F
F and H
G and H

Solutions:

A and B

Step 1: The contour interval given on the map is 20 ft.

Step 2: The map scale conversion factor from table II–10 for a scale of 1:24000 is 2,000 ft per inch.

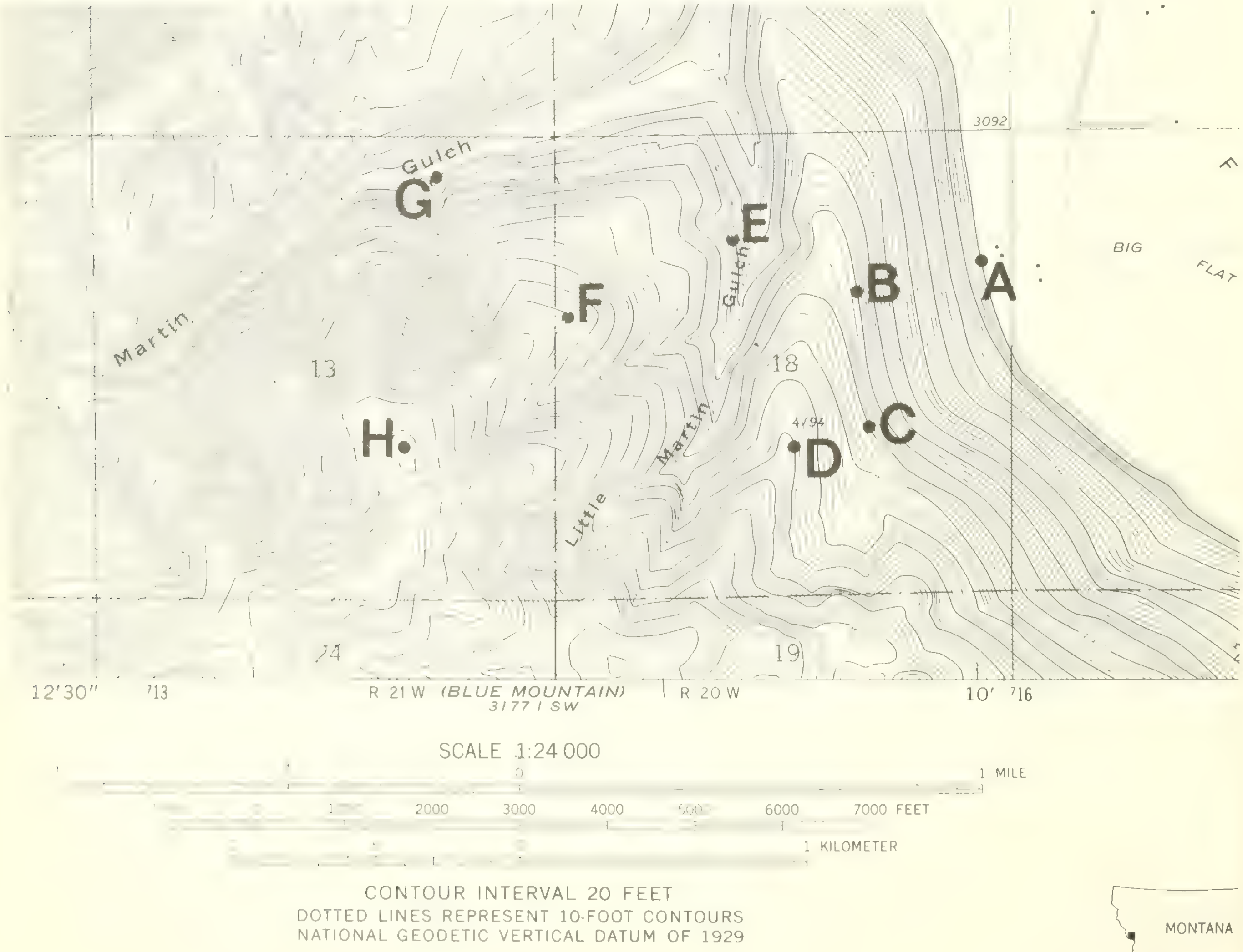
Step 3: There are 35 contour intervals between A and B. The rise in elevation is $35 \times 20 = 700$ ft.

Step 4: The distance between points A and B on the map is 0.72 inches. The horizontal distance is $0.72 \times 2{,}000 = 1{,}440$ ft.

Step 5: The slope is $\frac{\text{rise}}{\text{horz. dist.}} = \frac{700}{1{,}440} \times 100 = 49\%$.

C and D	Vertical rise	$= 15 \times 20$	= 300 ft
	Horizontal distance	$= 0.42 \times 2{,}000$	= 840 ft
	Slope	$= \frac{300}{840} \times 100$	= 36%
E and F	Vertical rise	$= 40 \times 20$	= 800 ft
	Horizontal distance	$= 1.5 \times 2{,}000$	= 3,000 ft
	Slope	$= \frac{800}{3{,}000} \times 100$	= 27%
F and H	Vertical rise	$= 31 \times 20$	= 620 ft
	Horizontal distance	$= 1.2 \times 2{,}000$	= 2,400 ft
	Slope	$= \frac{620}{2{,}400} \times 100$	= 26%
G and H	Vertical rise[10]	$= 5{,}030 - 3{,}500$	= 1,530 ft
	Horizontal distance	$= 1.55 \times 2{,}000$	= 3,100 ft
	Slope		= 49%

[10]In this example the difference in elevation between G and H rather than the number of contour intervals was used to determine the vertical rise.



CHAPTER III

CALCULATING FIRE BEHAVIOR

Fire Behavior Worksheets

The fire behavior worksheet (exhibit II-1) has been designed for use with both the nomograms and the TI-59 calculator. The sheet is intended for recording input data, showing the results of calculations, and displaying results needed for plotting fire growth and interpreting fire behavior. The reverse side of the worksheet is a form to estimate fine dead fuel moisture, using the tables described in the fuel moisture section.

INPUT DATA

Lines 1 through 18 provide the data required for calculations and lines 19 through 28 indicate the resulting fire behavior predictions. Values that are used as direct input to the TI-59 are indicated by the calculator overlay label abbreviation and the calculator register number. The keystroke sequence for obtaining output from the TI-59 is given on the worksheet.

The following is a line-by-line description of how to use the worksheet. This is followed by additional information concerning special uses of the worksheet.

Head – Enter the name of the fire.

Enter the name of the fire behavior officer or person responsible for predicting fire behavior.

Sequentially number the sheets and indicate the total number of sheets used to complete the fire growth for the overall time period.

Enter the date and time at which the calculations are made.

Because this is a forecast of expected fire behavior, record the date for which the forecast is made and the applicable time period for the calculations. Your fire experience and ability to interpret meteorological forecasts can contribute strongly here by helping you choose time intervals during which conditions are expected to be relatively constant.

All calculations made on one sheet should be for the same time interval. Use successive sheets for successive time intervals.

Line 1 – *Projection point.* A projection point is a place from which fire growth will be projected. (Refer to chapter IV, "Estimating Spread from a Line of Fire.")

Record the number of a projection point that will be associated with the same point on the map. All subsequent data in the column pertain to conditions in the direction of fire spread from that point.

Line 2 – *Fuel model proportion, pct*

If the two-fuel-model concept is being used, record an estimate of the proportion of the area that is covered by each fuel model. The fuel that covers most of the area should be placed in the second column. The sum of the two must total 100 percent. If one fuel model is used, leave this line blank.

Line 3 – *Fuel model*

Record the number of fuel model (13 available) that most closely matches the fuels ahead of the projection point.

If the fuels cannot be matched by one fuel model due to nonuniformity, use the two-fuel-model concept. Record the numbers of the fuel models in adjacent columns. (Refer to the two-fuel-model concept in the fuels section of chapter II.)

Line 4 – *Shade*

Enter a value of 0, 1, 2, or 3 based on shading due to either cloud or canopy cover or both for 0–10 percent, 10–50 percent, 50–90 percent, or 90–100 percent, respectively. This code is used by the TI-59 to calculate 1-hour fuel moisture. The tables for estimating fuel moisture only use an estimate of less than 50 percent shading or more than 50 percent shading.

Line 5 – *Dry bulb temperature,* °F

Enter the air temperature expected during the projection period.

Line 6 – *Relative humidity, pct*

Enter the relative humidity expected during the projection period.

RH is used in estimating fuel moisture from the tables and with the TI-59.

Line 7 – *1 H TL FM, pct*

Moisture of fine dead fuel determined from the tables can be used with either the nomograms or the TI-59. When used with the TI-59 it is equivalent to the 1-hour timelag fuel moisture. When the nomograms are used it is the only dead fuel moisture necessary, and lines 8 and 9 of the worksheet are not used.

Of the three dead fuel moisture values that can be entered for the TI-59, 1 H TL FM is by far the most important.

Line 8 – *10 H TL FM, pct*

If the TI-59 is being used, an estimate of the 10-hour timelag fuel moisture is needed for most fuel models. If a fire danger weather station is nearby, the fuel stick moisture content can be used for the 10 H TL FM. If there has been a long-term drying period, the 10 H TL FM can be assumed to be 1 or 2 percent wetter than the 1 H TL FM calculated for afternoon conditions.

Line 9 – *100 H TL FM, pct*

If the TI-59 is being used, enter an estimate for 100-hour timelag fuel moisture. In a long-term drying cycle, the 100-hour value can be estimated as 1 or 2 percent wetter than the 10-hour value.

Line 10 – *Live fuel moisture, pct*

Estimate live fuel moisture from the guides given in the fuel moisture section.

Line 11 – *20-ft windspeed, mi/h*

The standard height for measuring and forecasting wind is 20 ft above the vegetation. A value of the speed and direction must be carefully estimated by taking into account several rather subjective factors. See the section on wind in chapter II. If the tables for slope winds are used, the value obtained is the midflame windspeed and no 20-ft wind value or adjustment factor is necessary.

Line 12 – *Wind adjustment factor*
Enter the factor that is read from the wind adjustment table II–6. When the 20-ft windspeed is multiplied by the wind adjustment factor, the result is the midflame windspeed. If table II–5 is used, the wind adjustment factor is not entered.

Line 13 – *Midflame windspeed, mi/h*
If midflame windspeed is estimated from 20-ft windspeed, canopy cover, and topography, enter the value obtained by multiplying 20-ft windspeed (line 11) by the wind adjustment factor (line 12). Alternatively, an estimate of the midflame windspeed can be made without measurement or calculation with tables II–3 and II–5.

If a portable handheld anemometer is used to measure the windspeed near the fire and under the same sheltering conditions that the fire will experience, the measured value may be used directly as midflame windspeed for most fuels. For tall shrubs, 4–6 ft, the midflame wind should be measured at 8–10 ft above the ground rather than eye level.

Line 14 – *Maximum slope, pct*
Enter the maximum slope of the terrain above the projection point.

Line 15 – *Projection time, h*
Record the length of the projection time period; this time is determined as the difference between the beginning and ending time of the projection time recorded in the heading. Projection time is used to find spread distance, map distance, perimeter, and area (lines 23 through 26).

Line 16 – *Map scale, in/mi*
If the TI–59 is being used, enter the map scale in **inches per mile**.

If the nomograms are being used, leave this line blank.

Map scale is used only to calculate map distance (line 24).

Line 17 – *Map conversion factor, in/ch*
If nomograms are being used, enter the map conversion factor in inches per chain from the table below. To plot the spread distance from the nomograms on the map overlay, it is necessary to determine the number of inches equivalent to the spread distance in chains. The conversion factor can be calculated as follows:

Conversion factor = Map scale divided by 80 where the map scale is inches per mile.

Example: Map scale = 1/2 inch per mile
Map conversion factor = 0.5/80 = 0.00625

The following conversion table covers most standard map scales:

Map scale (inches/mi)	Conversion factor (inches/chain)
1/4	0.00312
1/2	.00625
1	.0125
2	.025
2-5/8	.0328
4	.05

If the TI–59 is being used, leave this line blank.

Line 18 – *Effective windspeed, mi/h*
If the nomograms are being used, use the lower left-hand quadrant to determine the effective windspeed from midflame windspeed (line 13) and maximum slope (line 14).

If the TI–59 is being used, leave this line blank.

FIRE BEHAVIOR OUTPUTS

The data assembled in lines 1 through 18 are used to calculate the fire behavior at each projection point. Either the nomograms or the TI–59 calculator can be used.

A description of the meaning of each of the outputs given on lines 19 to 28 of the fire behavior worksheet is given below:

Line 19 – *Rate of spread, ch/h*
The rate of advance of the "head" of a fire is called the forward rate of spread. (Computed by TI–59 and nomograms.)

Line 20 – *Heat per unit area, Btu/ft²*
This is the amount of heat released per square foot during the time that area is within the flaming front. The use of this intensity term will be explained in conjunction with the fire characteristics chart. (Computed by TI–59 and nomograms.)

Line 21 – *Fireline intensity, Btu/ft/s*
This is the amount of heat released (in Btu's) per foot of fire front per second. It is related to the difficulty of containment of a fire. Fireline intensity is based on both the rate of spread and the heat per unit area of the fire. (Computed by TI–59 and nomograms.)

Line 22 – *Flame length, ft*
This is the average length of the flame at the projection point (fig. III–1). Under no-wind, no-slope conditions, flame length and flame height are the same. Under strong winds or steep slopes there can be a significant difference. (Computed by TI–59 and nomograms.)

Flame length can be used as an alternative, observable measure of fireline intensity.

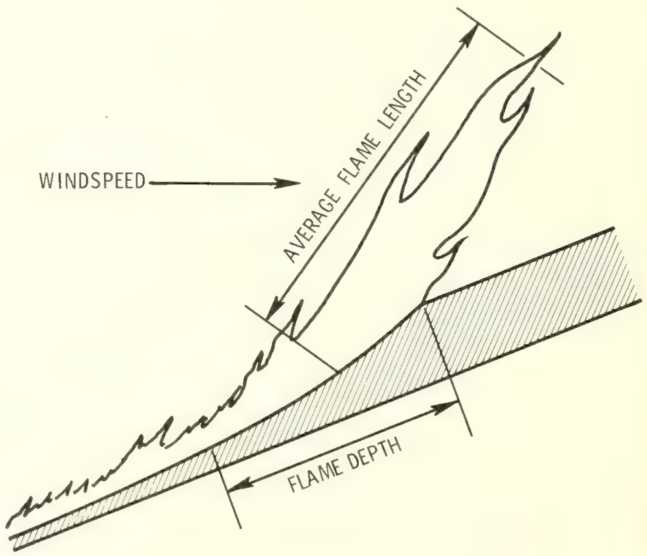


Figure III–1.—Depiction of flame dimensions.

Line 23 - *Spread distance, ch*

This is an estimate of the probable forward movement of the head of the fire during a specified time period. When nomograms are used, spread distance is obtained by multiplying rate of spread (line 19) by projection time (line 15). (Calculated directly by the TI-59.)

Line 24 - *Map distance, in*

This is an estimate of the progress of the fire front for mapping purposes. When nomograms are used, map distance is determined by multiplying spread distance (line 23) by the map conversion factor (line 17). (Calculated directly by TI-59.)

Line 25 - *Perimeter, ch*

This is an estimate of the perimeter of a fire started from a point and having a shape that is approximately elliptical. When nomograms are used it is determined from table IV-2. (Calculated directly by the TI-59.)

Line 26 - *Area, a*

This is an estimate of the area in acres of a fire started from a point source and having a shape that is approximately elliptical. When nomograms are used, it is obtained from table IV-3. (Calculated directly by the TI-59.)

Line 27 - *Ignition component, pct*

This is an estimate of the probability that a firebrand will cause an ignition that will evolve into a fire that is large enough to be "reportable." This is not the same as the probability of ignition which is discussed in chapter IV in the crowning and spotting section. Ignition component incorporates probability of ignition and rate of spread. (IC is calculated directly by the TI-59.)

Line 28 - *Reaction intensity, Btu/ft²/ min*

This is the rate of heat released per square foot per minute. It should not be confused with fireline intensity, which is the value usually associated with the intensity of a fire. Reaction intensity is an important output of the fire model and can be expected to be important for relating to fire effects. (It is calculated directly by the TI-59.) Methods for manual calculation are given in appendix C.

Calculating Fire Behavior With Nomograms

A nomogram is a group of interconnecting graphs that can be used to solve a mathematical equation or series of equations. Albini (1976) developed a set of nomograms for calculating fire behavior, utilizing the equations of Rothermel's fire model.

The nomograms presented here have been modified from Albini's original version. The primary change has been to use midflame windspeed, rather than 20-ft windspeed, as an input. Albini used 20-ft windspeed, with a wind reduction factor of one-half, which was the prevailing assumption at that time, to predict fire behavior in all conditions. To correct the overprediction of fire spread in cases where the fuels were sheltered by an overstory of trees, the method of calculating windspeed in sheltered fuel presented by Albini and Baughman (1979) was adopted (see "Wind," chapter II).

Another change was to replace reaction intensity with heat per unit area as one of the outputs.

There are two nomograms for each of the 13 fuel models: a low windspeed version and a high windspeed version. Both give the same answers, but better resolution can be obtained from the low windspeed version, so it should be used whenever possible. Nomograms for the 13 fire behavior fuel models are given in appendix A.

Nomograms will provide an estimate of rate of spread, fireline intensity, flame length, and heat per unit area. The fire behavior worksheet specifies the input data and is used to record the outputs. It has been designed for use with either the nomograms or the TI-59. Not all values are used with both systems; consequently, some lines on the fire behavior worksheet will not be used. Whenever the worksheet is needed, the line number on the left-hand margin will be referred to.

For the nomograms, data on the following lines are necessary:

- 3 Fuel model
- 7 Fine dead fuel moisture
- 10 Live fuel moisture for some fuels
- 13 Midflame windspeed
- 14 Maximum slope

Fuel models 2, 4, 5, 7, and 10 contain living fuel. The procedures for fuels with live fuel moisture are somewhat different than for the fuel models that have only dead fuel. Methods for calculating fire behavior with fuel models containing only dead fuels will be covered first.

It is assumed that a worksheet (exhibit III-1) has been prepared with the required information. Select the nomogram for the fuel model designated on line 3 of the fire behavior worksheet.

There are four parts to the nomogram. These are called quadrants and are referred to as "upper" and "lower" (referring to the top and bottom of the page) and by "left" and "right." Solving a fire spread problem on a nomogram requires initial preparation followed by a run through all four quadrants, with a continuous line starting and finishing in the upper right quadrant. All of the answers are read in the upper right quadrant. Solutions for the examples given in exhibit III-1 are shown on exhibits III-2 and III-3.

The nomogram should be placed on a flat surface. Lines should be drawn with a narrow 10- or 12-inch transparent straightedge or ruler. The underlying 1/4-inch grid should be used to keep your lines true with those on the nomogram, i.e., parallel and forming right angles at intersections.

Exhibit III-1.—Fire behavior worksheet with examples for nomograms.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Old Smokey FIRE BEHAVIOR OFFICER Flaming Aero

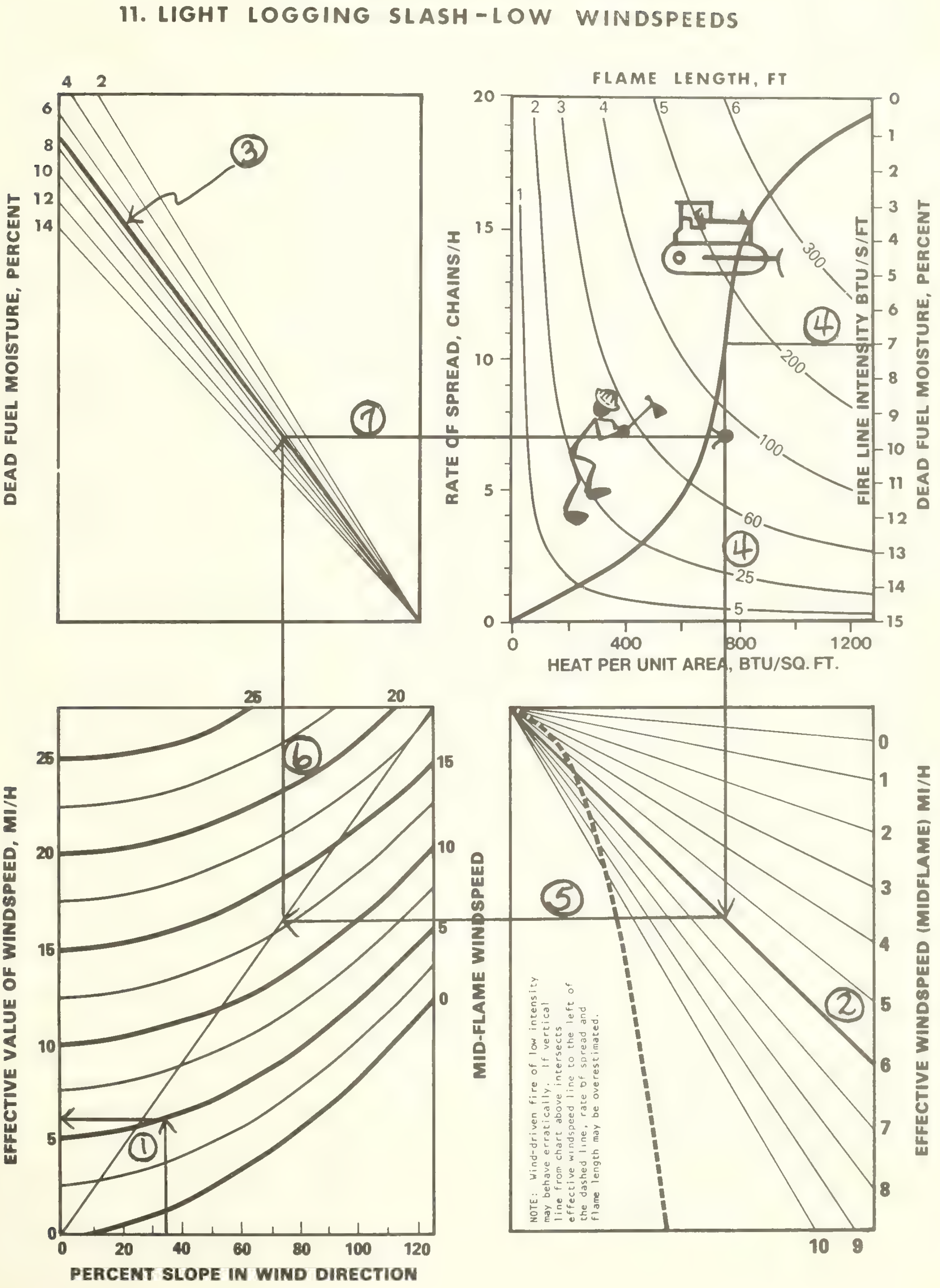
DATE 12/4/81 TIME 1420

PROJ. PERIOD DATE 12/5/81 PROJ. TIME FROM 1200 to 1400

INPUT DATA			Dead Fuel Example		Live Fuel Example		TI-59 Reg. No.
1	Projection point		①		②		
2	Fuel model proportion, %		100		100		
3	Fuel model		11		5		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0		0		60
5	Dry bulb temperature, °F	DB	55		55		61
6	Relative humidity, %	RH	22		22		62
7	1 H TL FM, %	1H	7		7		28
8	10 H TL FM, %	10H	7		7		63
9	100 H TL FM, %	100H	7		7		30
10	Live fuel moisture, %	LIVE	-		200		33
11	20-foot windspeed, mi/h		(12)	( )	(12)	( )	
12	Wind adjustment factor		(.4)	( )	(.4)	( )	
13	Midflame windspeed, mi/h	M WS	5		5		79
14	Maximum slope, %	PCT S	35		35		80
15	Projection time, h	PT	2		2		81
16	Map scale, in/mi	MS	-		-		82
17	Map conversion factor, in/ch		-		-		
18	Effective windspeed, mi/h		6		6		

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	7		7		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	760		240		90
21	Fireline intensity, Btu/ft/s	[B]	INT	85		30		53
22	Flame length, ft	[R/S]	FL	4		2		54
23	Spread distance, ch	[C]	SD	14		14		42
24	Map distance, in	[R/S]	MD	-		-		43
25	Perimeter, ch	[D]	PER	-		-		40
26	Area, acres	[R/S]	AREA	-		-		89
27	Ignition component, %	[E]	IC	-		-		44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	-		-		52

Exhibit III-2.—Example of nomogram solution with dead fuel only.



GENERAL INSTRUCTIONS—EITHER LIVE OR DEAD FUEL

Step 1.—Determine effective value of the midflame windspeed. (This step combines wind and slope.) Note the slope given on line 14 of the fire behavior worksheet. In the lower left quadrant, find the percent slope and draw a vertical line to the top of the quadrant. On the right-hand side of the lower left quadrant, find the midflame windspeed given on line 13 of the fire behavior worksheet. Follow the curved windspeed line until it intercepts the vertical line just drawn. At the intersection, draw a horizontal line to the left-hand margin. The effective windspeed is read off the margin. For the example in exhibit III-2 the effective windspeed is 6 mi/h. Record the effective midflame windspeed on line 18 of the fire behavior worksheet.

The construction lines drawn in the lower left quadrant are not used again.

Step 2.—Prepare the lower right quadrant by locating a ray (line from the origin) that represents the effective windspeed. Such lines are already in the quadrant to guide you. Interpolate if necessary to establish a ray for the effective windspeed determined in step 1. This line will be used later as a turning line when taking the run through the nomogram.

Note: The lower right quadrant contains a curved dashed line. A note in this quadrant reads:

> Wind-driven fires of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and fireline intensity may be overstated.

If the vertical line from the upper right quadrant intersects the curved dashed line before reaching the designated effective windspeed ray, stop at the intersection with the dashed line and draw a line into the lower left quadrant from that intersection. This will produce a lower rate of spread and fireline intensity than would result if you continued past the curved dashed line and used the designated effective windspeed line.

FUEL MODELS WITH DEAD FUELS ONLY

Step 3.—For nomograms with no live fuel. This step prepares the upper left quadrant. On the edge of the quadrant find the dead fuel moisture value given on line 7 of the fire behavior worksheet. If necessary to interpolate, construct a new ray for this fuel moisture.

All preparations have been made and you can begin your run around the nomogram.

Step 4.—Begin in the upper right quadrant. In the right hand margin locate the dead fuel moisture from line 7 of the fire behavior worksheet. Draw a horizontal line across the upper right quadrant until it intercepts the S-shaped curve. Through this interception draw a vertical line from the top of the upper right quadrant into the lower right quadrant until it meets the ray designating the effective windspeed or intercepts the curved dashed line as described in step 2 (see exhibit III-2).

Step 5.—Note the diagonal line in the lower left quadrant. This is the next turning line. From the interception of the effective windspeed in the lower right quadrant, draw a horizontal line into the lower left quadrant where it intercepts the diagonal line. (Pay no attention to the previously constructed lines from step 1 in the lower left quadrant.)

Step 6.—At the intersection of the turning line in the lower left quadrant draw a vertical line into the upper left quadrant until it intercepts the appropriate ray for the fuel moisture found in step 3 (see exhibit III-2).

Step 7.—At the intercept with the dead fuel moisture ray in the upper left quadrant, draw a horizontal line into the upper right quadrant, extending it until it intercepts the vertical line constructed in step 4 at the beginning of the run. Draw a small circle at this intercept (see exhibit III-2).

You have run the line through all four quadrants; you can now read the answers.

Rate of spread.—Read at the left-hand margin of the upper right quadrant where the horizontal line from step 7 enters the quadrant. In exhibit III-2, the rate of spread is 7 ch/h. Record rate of spread on line 19 of the fire behavior worksheet.

Fireline intensity.—Determine from the small circle drawn in step 7 in the upper right quadrant. The fireline intensity numbers are indicated on each curved line running through the quadrant. Interpolate between lines. In exhibit III-2, the fireline intensity is about 85 Btu/ft/s. Record fireline intensity on line 21 of the fire behavior worksheet.

Flame length.—The small circle drawn in step 7 lies on, near, or between the family of curved lines; follow the nearest line to the top of the upper right quadrant and see the flame lengths marked in feet. Use the location of the circle between these lines to estimate flame length. Do not be exact. The nearest foot is sufficient in most cases. In exhibit III-2, the flame length is about 4 ft. Record flame length on line 22 of the fire behavior worksheet.

Heat per unit area.—Read on the lower horizontal axis of the upper right quadrant where it is crossed by the vertical line drawn in step 4. In exhibit III-2, the heat per unit area is 760 Btu/ft^2.

After some practice you will find that it is only necessary to draw lines in the upper right quadrant when you make the trip around the nomogram; tic marks at intersections in the other quadrants are sufficient.

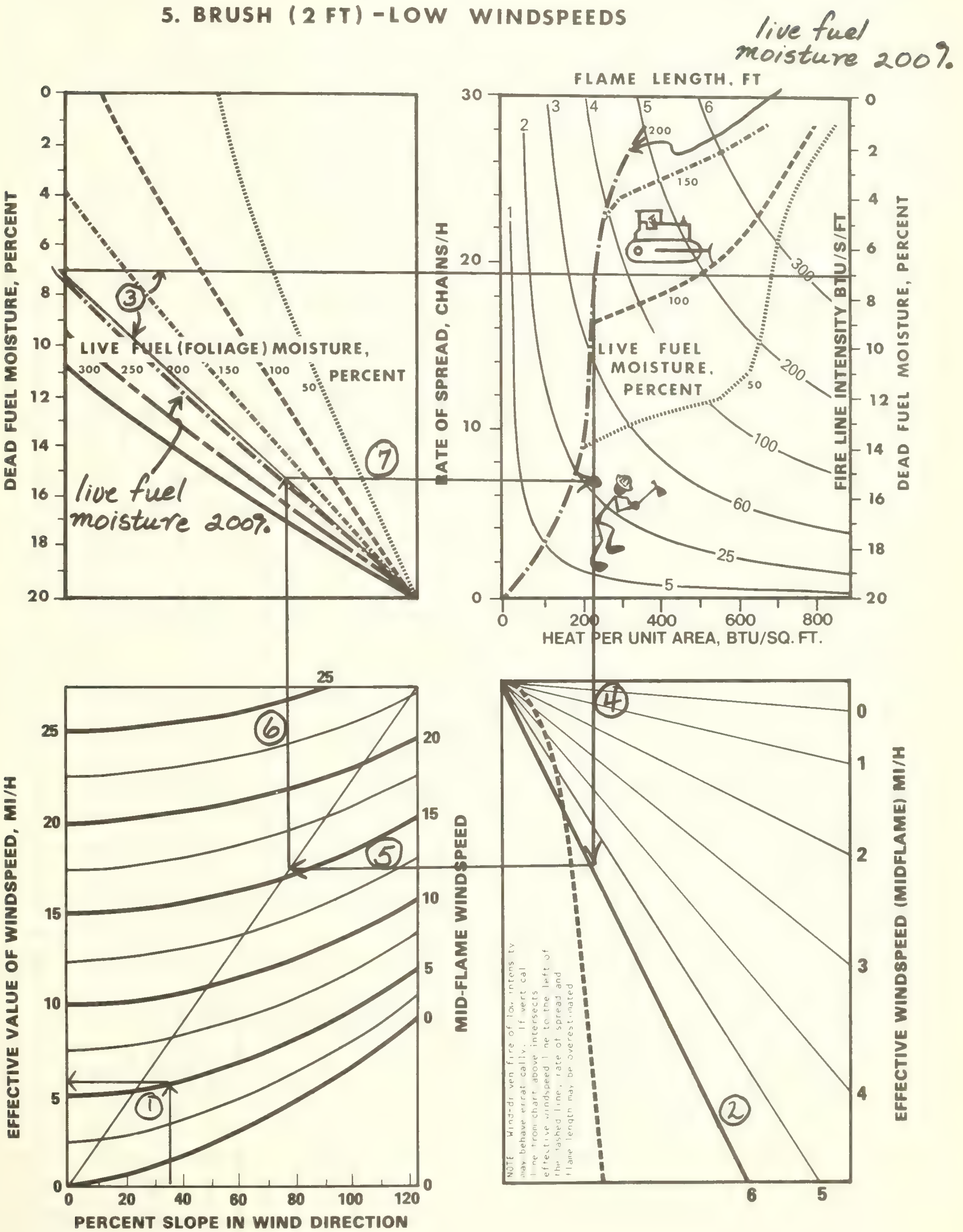
FUEL MODELS WITH LIVE AND DEAD FUELS

Fuel models 2, 4, 5, 7, and 10 have living fuels requiring a different procedure in step 3. Do not be discouraged; Albini has designed the nomograms to account for this extra variable with little extra effort.

Step 3 with live fuel.—Find the dead fuel moisture on the right side of the upper right quadrant and on the left side of the upper left quadrant. Draw a line across both quadrants at the designated dead fuel moisture. See the worked example in exhibit III-3. In the upper left quadrant find the intersection of the horizontal line just drawn with a slightly curved line representing the live fuel moisture given on line 10 of the fire behavior worksheet. Lay your straightedge between the intersection just found and the origin and draw a ray out to the margin as shown in exhibit III-3. This line will be the turning ray in the upper left quadrant when you make your run around the nomogram (exhibit III-3). Note that for some fuel models and some conditions the slightly curved lines are so straight that this step provides little correction.

Step 4 with live fuels.—Locate the S-shaped curve that comes the closest to matching the live fuel moisture at the start of your run in the upper right quadrant. You can interpolate between these lines if desired. The run will end at the intersection of this vertical line. All other steps are the same as used for dead fuel.

Exhibit III-3.—Example of nomogram solution with live and dead fuels.



INTERPRETATION OF CURVES DISPLAYED ON THE NOMOGRAMS

Note that the more severe the fire conditions are, i.e., dry fuels, high winds, the further you will be from the origin or center of the paper as you travel around the nomogram.

Note the effect of the S-shaped curve in the upper right nomogram. When fuels are very dry, i.e., less than 5 percent, the line curves away from the center quite sharply, which will produce high intensities. When the fuel becomes wet the line drops sharply to the origin. This is a region of uncertain fire behavior because of the very wet fuels. The moisture of extinction can be read off the bottom of the right-hand margin where the curve reaches zero. This is the moisture at which fire can no longer spread with a sustained fire front. It will be different for different fuel models.

In the lower right quadrant note the curved dashed line. This line designates a limiting windspeed at which a further increase in windspeed would not necessarily make the fire spread faster. The limit is set by the reaction intensity which for each fuel model is set by the fuel moisture. If the reaction intensity becomes too low, the wind will overpower the flame and blow it into fingers of fire that will be cooled, diluted, and eventually blown out.

The influence of wind and slope upon fire behavior and their respective effects can be seen in the lower left quadrant. At low windspeeds an increase in slope produces a higher effective windspeed than it does at higher windspeeds.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 2

NAME OF FIRE *Nomogram Exercises* FIRE BEHAVIOR OFFICER ______

DATE ______ TIME ______

PROJ. PERIOD DATE ______ PROJ. TIME FROM ______ to ______

INPUT DATA *Only the direct inputs needed to calculate the first four outputs with the nomograms are given.*

								TI-59 Reg. No.
1	Projection point		*Exercise No.*	1	2	3	4	
2	Fuel model proportion, %			100	100	100	100	
3	Fuel model			6	1	3	9	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE					60
5	Dry bulb temperature, °F		DB					61
6	Relative humidity, %		RH					62
7	1 H TL FM, %		1H	4	8	12	22	28
8	10 H TL FM, %		10H					63
9	100 H TL FM, %		100H					30
10	Live fuel moisture, %		LIVE					33
11	20-foot windspeed, mi/h			( )	( )	( )	( )	
12	Wind adjustment factor			( )	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	0	5	25	20	79
14	Maximum slope, %		PCT S	60	20	60	0	80
15	Projection time, h		PT					81
16	Map scale, in/mi		MS					82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h			3	5	26	20	

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	23	87	700	8	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	530	80	650	170	90
21	Fireline intensity, Btu/ft/s	[B]	INT	250	140	8300	15	53
22	Flame length, ft	[R/S]	FL	5 1/2	4 1/2	29	1	54
23	Spread distance, ch	[C]	SD					42
24	Map distance, in	[R/S]	MD					43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 2

NAME OF FIRE Nomogram Exercises FIRE BEHAVIOR OFFICER ____

DATE ____ TIME ____

PROJ. PERIOD DATE ____ PROJ. TIME FROM ____ to ____

INPUT DATA

							TI-59 Reg. No.
1	Projection point		5	6			
2	Fuel model proportion, %		100	100			
3	Fuel model		10	5			
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE					60
5	Dry bulb temperature, °F	DB					61
6	Relative humidity, %	RH					62
7	1 H TL FM, %	1H	6	4			28
8	10 H TL FM, %	10H					63
9	100 H TL FM, %	100H					30
10	Live fuel moisture, %	LIVE	100	100			33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	12.5	10			79
14	Maximum slope, %	PCT S	60	60			80
15	Projection time, h	PT					81
16	Map scale, in/mi	MS					82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h		14	12			

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	35	80			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1400	700			90
21	Fireline intensity, Btu/ft/s	[B]	INT	850	1000			53
22	Flame length, ft	[R/S]	FL	10	11			54
23	Spread distance, ch	[C]	SD					42
24	Map distance, in	[R/S]	MD					43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

Calculating Fire Behavior with the TI-59 Calculator

GENERAL

The TI-59 handheld calculator contains a small interchangeable module. Two thousand modules preprogramed to compute fire behavior were distributed to fire management agencies throughout the country. The program is explained in the user's manual prepared by Burgan (1979). Instructions for operating the calculator are not repeated in this manual except where new material has been added or clarification is needed. A copy of Burgan's manual[1] should be available for everyone using a chip. A 3-day training session on operation of the TI-59 with the chip was developed at the Northern Forest Fire Laboratory[2] for persons receiving the chip. The operating instruction summary used in that course is shown in exhibit III-4. These are instruction summaries and should not be used as sequential procedures. A copy of the keyboard overlay is given in exhibit III-5. It is important to know which inputs affect which outputs so that the calculator can be operated efficiently and changes made quickly. A matrix showing the interactions is given in exhibit III-6. This manual is compatible with material presented in the TI-59 training course.

The TI-59 fire behavior chip utilizes the same fire behavior worksheet used with the nomograms (exhibit II-1). The inputs utilized by the chip are identified by the lines that have an overlay label and register number alongside.

Exhibit III-4.—TI-59 operating instruction reminder.

FIRE BEHAVIOR COMPUTATIONS

Select program and enter fuel model	2nd PGM 2 SBR R/S (display = -4.) *fuel model number* R/S
Enter input	*value* SBR KEY
Check input	SBR 2nd KEY
Obtain output	A R/S B R/S C R/S D R/S E R/S
Check input or output	RCL *register number*
Change fuel model	SBR R/S (display = -4.) *fuel model number* R/S
Display all decimals	INV 2nd (
Set number of decimal places	2nd (*number of places*
Check all input and obtain output	SBR 2nd SHADE R/S R/S ... R/S
Calculate 1 H and 10 H	*value* SBR SHADE *value* SBR DB 0 SBR 10 H *value* SBR RH (must proceed next step) R/S (1 H is displayed) SBR 2nd 10 H (10 H is displayed)
Calculate 1 H when 10 H is known	*value* SBR SHADE *value* SBR DB *value* SBR 10 H *value* SBR RH (must proceed next step) R/S (1 H is displayed)

[1]Copies obtainable from Intermountain Forest and Range Experiment Station, Research Information, 507 25th St., Ogden, UT 84401. Ask for Fire Danger/Fire Behavior Computations with the Texas Instruments TI-59 Calculator: User's Manual, USDA For. Serv. Gen. Tech. Rep. INT-61.

[2]Unpublished instructions for calculating the NFDRS indexes and fire behavior, by Andrews, Burgan, and Rothermel.

Exhibit III-5.—TI-59 fire behavior keyboard overlay.

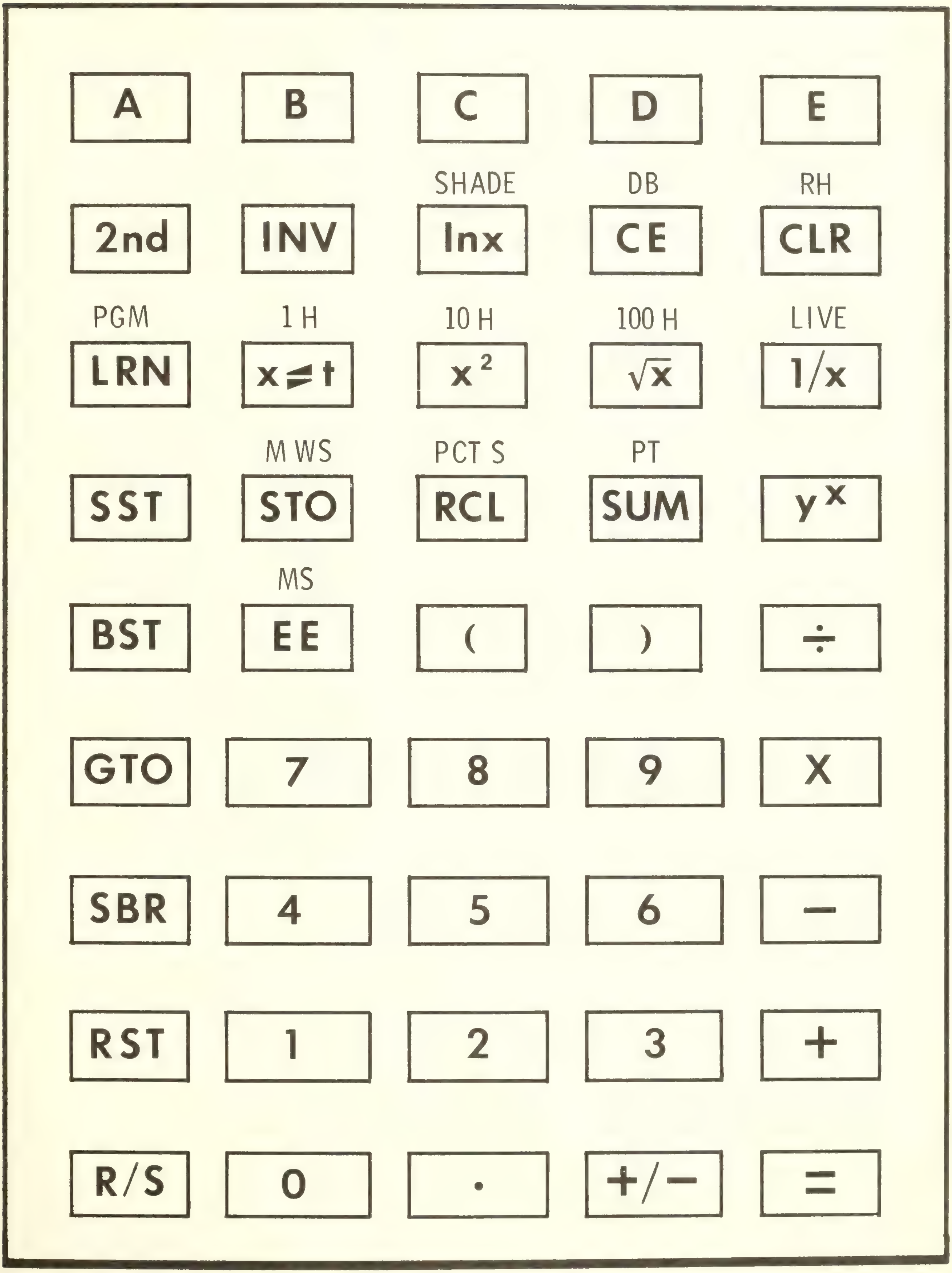


Exhibit III-6.—Interaction matrix between inputs and outputs.

CALCULATED OR OUTPUT VALUES

INPUT VALUES		1-hour timelag fuel moisture 1 H[1]	10-hour timelag fuel moisture 10 H[1]	Rate of spread ROS	Heat per unit area H/A	Fireline intensity INT	Flame length FL	Spread distance SD	Map distance MD	Perimeter PER	Area AREA	Ignition component IC	Reaction intensity IR
Fuel model				X	X	X	X	X	X	X	X	X	X
Fuel shading	SHADE	X	X									X	
Dry bulb temperature	DB	X	X									X	
Relative humidity	RH	X	X										
1-H timelag fuel moisture	1 H			X	X	X	X	X	X	X	X	X	X
10-H timelag fuel moisture	10 H[2]	X[3]		X	X	X	X	X	X	X	X	X	X
100-H timelag fuel moisture	100 H[2]			X	X	X	X	X	X	X	X	X	X
Live fuel moisture	LIVE[2]			X	X	X	X	X	X	X	X	X	X
Midflame windspeed	M WS			X		X	X	X	X	X	X	X	
Percent slope	PCT S			X		X	X	X	X	X	X	X	
Projection time	PT							X	X	X	X		
Map scale	MS								X				

[1]Optional calculation
[2]Only for fuel models that include these fuel components
[3]Whenever a non-zero value is stored for 10 H TL FM

The TI-59 produces the 10 outputs listed on lines 19 through 28. Interpretation of these outputs is given in chapter IV.

As a reminder, it is not necessary to reenter all inputs when one input is changed. The old entries will remain if they are not specifically changed. This is true of fuel model selection as well. Review Burgan's manual carefully regarding change of inputs.

Similarly, if you are only interested in rate of spread and flame length you need only look at the first four outputs before making a change for a new calculation.

Several examples for using the TI-59 complete with answers follow this section.

Calculating Fire Behavior in Nonuniform Fuels

(The Two-Fuel-Model Concept)

Three columns of the fire behavior worksheet should be used when the two-fuel-model concept is being employed: one column for each fuel model and one column for combined calculation of spread. Enter the fuel model with the largest proportion of fuel in the second column. The fuel model proportion, line 2 of the fire behavior worksheet, is estimated for each fuel model. The two percentages should total 100 percent. The fire behavior calculations are carried out as usual and the results recorded on the worksheet. The rate of spread is weighted by percent cover and recorded in the third column.

Do not try to combine fireline intensities or flame lengths. Unlike rate of spread, which may be averaged over some time to find the spread distance, intensity is important at the time it occurs and should not be averaged or weighted. As a first approximation, simply estimate that the intensity values calculated separately will exist in the same proportion as the estimated cover of each fuel model.

When using the TI-59, the entire operation can be performed with a few keystrokes. The weighted value for rate of spread is then stored in register 88, where it is used to calculate new values of spread distance, map distance, area, and perimeter. The example below and the accompanying worksheet illustrate the process.

EXAMPLE OF THE TWO-FUEL-MODEL CONCEPT PROCEDURES

Results are recorded on the accompanying fire behavior worksheet.

Fuel model 5; 30% cover; rate of spread = 25 ch/h
Fuel model 1; 70% cover; rate of spread = 99 ch/h

Determine weighted rate of spread by the following keystroke sequence:

$$0.3 \times 25 + 0.7 \times 99 = 77$$

STO 88

The weighted rate of spread is now stored in the rate of spread register (88). Do not hit button **A** or the calculator will recalculate rate of spread and erase the value just stored in register 88. Instead, utilize the weighted rate of spread now stored in register 88 to calculate the spread distance, map distance, perimeter, and area with the following keystrokes:

C	read spread distance (chains) in display
R/S	read map distance (inches) in display
D	read perimeter (chains) in display
R/S	read area (acres) in display.

The completed example is shown on the accompanying worksheet.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Two-fuel-model example FIRE BEHAVIOR OFFICER ______

DATE ______ TIME ______

PROJ. PERIOD DATE ______ PROJ. TIME FROM ______ to ______

INPUT DATA For simplicity, only those inputs and outputs used in the example are shown

								TI-59 Reg. No.
1	Projection point		1	1	1			
2	Fuel model proportion, %		30	70				
3	Fuel model		5	1				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE						60
5	Dry bulb temperature, °F	DB						61
6	Relative humidity, %	RH						62
7	1 H TL FM, %	1H	5	5				28
8	10 H TL FM, %	10H	–	6				63
9	100 H TL FM, %	100H	–	–				30
10	Live fuel moisture, %	LIVE	–	100				33
11	20-foot windspeed, mi/h		( )	( )	( )	( )		
12	Wind adjustment factor		( )	( )	( )	( )		
13	Midflame windspeed, mi/h	M WS	5	5				79
14	Maximum slope, %	PCT S	0	0				80
15	Projection time, h	PT	1	1				81
16	Map scale, in/mi	MS	1	1				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

OUTPUT DATA

19	Rate of spread, ch/h	[A] ROS	25	99	77			88
20	Heat per unit area, Btu/ft^2	[R/S] H/A	654	92				90
21	Fireline intensity, Btu/ft/s	[B] INT	297	168				53
22	Flame length, ft	[R/S] FL	6	5				54
23	Spread distance, ch	[C] SD			76.8			42
24	Map distance, in	[R/S] MD			1.0			43
25	Perimeter, ch	[D] PER			236			40
26	Area, acres	[R/S] AREA			376			89
27	Ignition component, %	[E] IC						44
28	Reaction intensity, Btu/ft^2/min	[R/S] IR						52

FIRE BEHAVIOR WORKSHEET

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER ______

DATE ______ TIME ______

PROJ. PERIOD DATE ______ PROJ. TIME FROM ______ to ______

INPUT DATA For simplicity, all input values are assumed including the fuel moisture.

No.	Item	Key		Exercise No. 1	2	3	4	TI-59 Reg. No.
1	Projection point			1	2	3	4	
2	Fuel model proportion, %			100	100	100	100	
3	Fuel model			5	6	3	5	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0	2	1	0	60
5	Dry bulb temperature, °F		DB	80	72	60	80	61
6	Relative humidity, %		RH	20	18	25	20	62
7	1 H TL FM, %		1H	4	8	10	3	28
8	10 H TL FM, %		10H	5	7	–	5	63
9	100 H TL FM, %		100H	–	5	–	–	30
10	Live fuel moisture, %		LIVE	90	–	–	100	33
11	20-foot windspeed, mi/h			( )	( )	( )	( )	
12	Wind adjustment factor			( )	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	4	2	0	0	79
14	Maximum slope, %		PCT S	30	0	5	0	80
15	Projection time, h		PT	.75	1	1	1	81
16	Map scale, in/mi		MS	4	1	1	1	82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							
	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	26	10	4	1	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	717	441	662	733	90
21	Fireline intensity, Btu/ft/s	[B]	INT	339	79	47	17	53
22	Flame length, ft	[R/S]	FL	7	3	3	2	54
23	Spread distance, ch	[C]	SD	19.3	9.8	3.8	1.3	42
24	Map distance, in	[R/S]	MD	1.0	0.1	0.05	0.0	43
25	Perimeter, ch	[D]	PER	61	36	16	6	40
26	Area, acres	[R/S]	AREA	25	10	2	.24	89
27	Ignition component, %	[E]	IC	64	12	3	17	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	3142	1796	2585	3211	52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 4

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER ____

DATE ____ TIME ____

PROJ. PERIOD DATE ____ PROJ. TIME FROM ____ to ____

INPUT DATA For simplicity, all inputs have been assumed including fuel moisture.

			Exercise No.				TI-59 Reg. No.
1	Projection point		5	6	7	8	
2	Fuel model proportion, %		100	100	100	100	
3	Fuel model		5	5	9	9	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0	0	0	0	60
5	Dry bulb temperature, °F	DB	80	80	80	80	61
6	Relative humidity, %	RH	20	20	20	20	62
7	1 H TL FM, %	1H	3	3	3	3	28
8	10 H TL FM, %	10H	5	5	5	5	63
9	100 H TL FM, %	100H	–	–	7	7	30
10	Live fuel moisture, %	LIVE	100	100	–	–	33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	5	10	0	5	79
14	Maximum slope, %	PCT S	0	0	0	0	80
15	Projection time, h	PT	1	1	1	1	81
16	Map scale, in/mi	MS	1	1	1	1	82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	28	72	1	12	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	733	733	448	448	90
21	Fireline intensity, Btu/ft/s	[B]	INT	376	961	9	97	53
22	Flame length, ft	[R/S]	FL	7	11	1	4	54
23	Spread distance, ch	[C]	SD	28	71.5	1.1	11.9	42
24	Map distance, in	[R/S]	MD	0.4	0.9	0	0.1	43
25	Perimeter, ch	[D]	PER	86	185	5	36	40
26	Area, acres	[R/S]	AREA	50	169	0	9	89
27	Ignition component, %	[E]	IC	77	83	18	57	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	3211	3211	2899	2899	52

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER

DATE TIME

PROJ. PERIOD DATE PROJ. TIME FROM to

For simplicity, all input values have been assumed including fuel moisture.

INPUT DATA

							TI-59 Reg. No.
1	Projection point Exercise No.		9	10	11	12	
2	Fuel model proportion, %		100	100	100	100	
3	Fuel model		9	3	3	3	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0	1	1	1	60
5	Dry bulb temperature, °F	DB	80	75	75	75	61
6	Relative humidity, %	RH	20	20	20	20	62
7	1 H TL FM, %	1H	3	2	5	10	28
8	10 H TL FM, %	10H	5	–	–	–	63
9	100 H TL FM, %	100H	7	–	–	–	30
10	Live fuel moisture, %	LIVE	–	–	–	–	33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	10	3	3	3	79
14	Maximum slope, %	PCT S	0	5	5	5	80
15	Projection time, h	PT	1	1	1	1	81
16	Map scale, in/mi	MS	1	1	1	1	82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	36	97	69	49	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	448	980	783	662	90
21	Fireline intensity, Btu/ft/s	[B]	INT	300	1736	987	596	53
22	Flame length, ft	[R/S]	FL	6	14	11	9	54
23	Spread distance, ch	[C]	SD	36.5	96.6	68.8	49.1	42
24	Map distance, in	[R/S]	MD	0.5	1.2	0.9	0.6	43
25	Perimeter, ch	[D]	PER	94	330	235	168	40
26	Area, acres	[R/S]	AREA	44	799	405	207	89
27	Ignition component, %	[E]	IC	83	56	30	11	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	2899	3825	3059	2585	52

FIRE BEHAVIOR WORKSHEET

Sheet 4 of 4

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER ______

DATE ______ TIME ______

PROJ. PERIOD DATE ______ PROJ. TIME FROM ______ to ______

For simplicity, all input values have been assumed including fuel moisture.

INPUT DATA							TI-59 Reg. No.
1	Projection point	Exercise No.	13	14	15		
2	Fuel model proportion, %		100	100	100		
3	Fuel model		1	1	1		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0	0	0		60
5	Dry bulb temperature, °F	DB	80	80	80		61
6	Relative humidity, %	RH	20	20	20		62
7	1 H TL FM, %	1H	3	3	3		28
8	10 H TL FM, %	10H	–	–	–		63
9	100 H TL FM, %	100H	–	–	–		30
10	Live fuel moisture, %	LIVE	–	–	–		33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	0	5	10		79
14	Maximum slope, %	PCT S	0	0	0		80
15	Projection time, h	PT	1	1	1		81
16	Map scale, in/mi	MS	1	1	1		82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	5	119	446		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	103	103	103		90
21	Fireline intensity, Btu/ft/s	[B]	INT	10	226	844		53
22	Flame length, ft	[R/S]	FL	1	5	10		54
23	Spread distance, ch	[C]	SD	5.3	119	446		42
24	Map distance, in	[R/S]	MD	0.1	1.5	5.6		43
25	Perimeter, ch	[D]	PER	23	367	1164		40
26	Area, acres	[R/S]	AREA	4	909	6919		89
27	Ignition component, %	[E]	IC	10	49	83		44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	939	939	939		52

CHAPTER IV

INTERPRETING FIRE BEHAVIOR AND PREDICTING FIRE GROWTH

Fire Characteristics Chart

The calculations displayed on the fire behavior worksheet have definite meanings and interpretations. Their meaning, however, is not always easy to understand, especially when many numbers are displayed at once. Several methods have been developed to aid interpretation and understanding of the numbers. One of these is a map of fire growth; another is the fire characteristics chart developed by Andrews and Rothermel (1982). The fire characteristics chart (fig. IV–1) has the unique capability of displaying four basic fire characteristics—rate of spread, heat per unit area, flame length, and fireline intensity—as a single point on a chart. Referring to figure IV–1, rate of spread is plotted on the vertical axis and heat per unit area on the horizontal axis. The curved lines represent fireline intensity and flame length. It is interesting to examine the severity (fire severity is used in a general sense; no specific definition is intended) of fires on the chart. If the heat released per unit area is taken as the measure of severity, then fires that plot further to the right are more severe. If rate of spread is the accepted measure of severity, then fires that plot highest on the graph are more severe. If fireline intensity or flame length is the measure (as is done in the National Fire Danger Rating System where it is expressed as the burning index), then fires that plot in bands of equal flame length successively farther from the origin are more severe. In general, the farther a fire's position from the origin, the more severe it will be in terms describing the behavior of surface fires.

Many fires or projection points from a single fire can be plotted on the same chart. A quick glance will explain differences in fire behavior. Fast-spreading fires with low intensity will lie near the vertical axis, illustrating the threat is due to rapid spread. High-intensity, slow-spreading fires such as might occur in old logging slash, will lie to the right near the horizontal axis. Fast-spreading fires with high intensity, such as produced by chaparral or red slash, will lie in the center of the graph well away from the origin.

Interpretations of fireline intensity and flame length in terms of difficulty of control and potential for severe fire behavior (Roussopoulos and Johnson 1975) as given in table IV–1 are illustrated by characters and color shadings on some fire characteristics charts.

The order in which the output values are displayed by the TI-59 calculator makes it easy to use the fire characteristics chart. Rate of spread, the first output, is located on the vertical axis. Heat per unit area, the second output, is located on the horizontal axis. Intersection of lines drawn into the chart from these two points gives fireline intensity and flame length, which are the next two calculator outputs.

You will not be able to plot every fire behavior prediction on this graph. Some points will be beyond the scale. For those areas of the country that have fuels that tend to produce higher heat per unit area values, but lower spread rates, an alternative chart is available (fig. IV–2). The only difference between figure IV–1 and figure IV–2 is the length of the axis. If you want to have one chart that will accommodate all fires, a log scale version is available (fig. IV–3). Note that log scales are not linear and more care must be taken when interpreting the position of the points. Fires with high intensity will show little change in position for a significant change in intensity, whereas low-intensity fires which may be very similar will scatter all over the lower left corner.

Although fires are represented by single points on the chart, it must be remembered that this is only an estimate of fire behavior and a circle would be a better representation of the uncertainty of the calculation. The more nonuniform the fuels and the more uncertainty about the weather forecast, the larger the circle should be. There is no simple way to calculate the uncertainty that is applicable for field use.

Examples of the use of the fire characteristics chart will be given later in this chapter.

Table IV–1.— Fire suppression interpretations.[1] CAUTION: These are not guides to personal safety. Fires can be dangerous at any level of intensity. Wilson (1977) has shown that most fatalities occur in light fuels on small fires or isolated sectors of large fires

Flame length	Fireline intensity	Interpretations
Feet	*Btu/ft/s*	
<4	<100	Fires can generally be attacked at the head or flanks by persons using handtools. Hand line should hold the fire.
4–8	100–500	Fires are too intense for direct attack on the head by persons using handtools. Hand line cannot be relied on to hold fire. Equipment such as dozers, pumpers, and retardant aircraft can be effective.
8–11	500–1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
>11	>1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

[1]Based on: Roussopoulos, Peter J.; Johnson, Von J. Help in making fuel management decisions. Res. Pap. NC-112. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1975. 16 p.

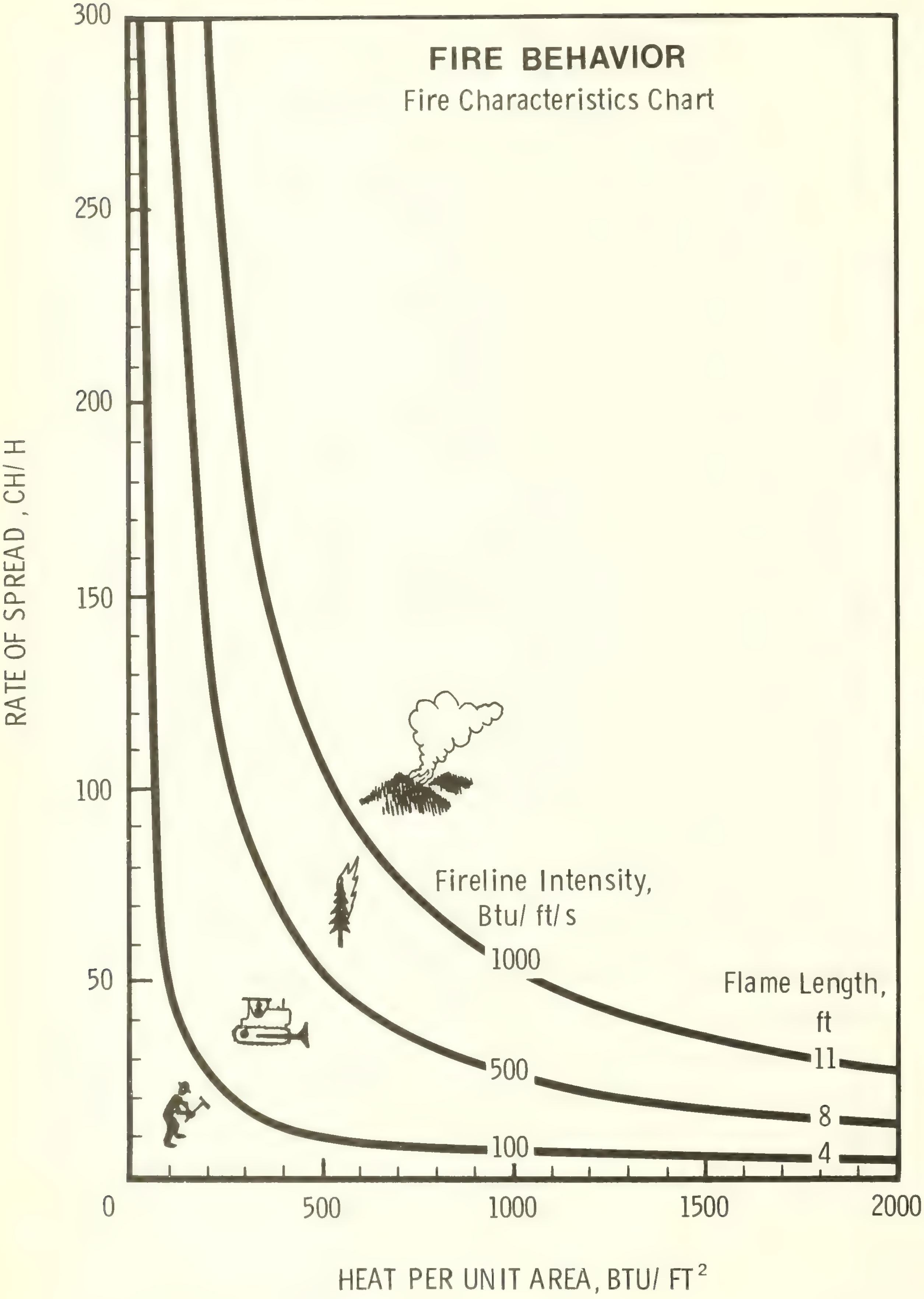


Figure IV-1.—Fire behavior fire characteristics chart.

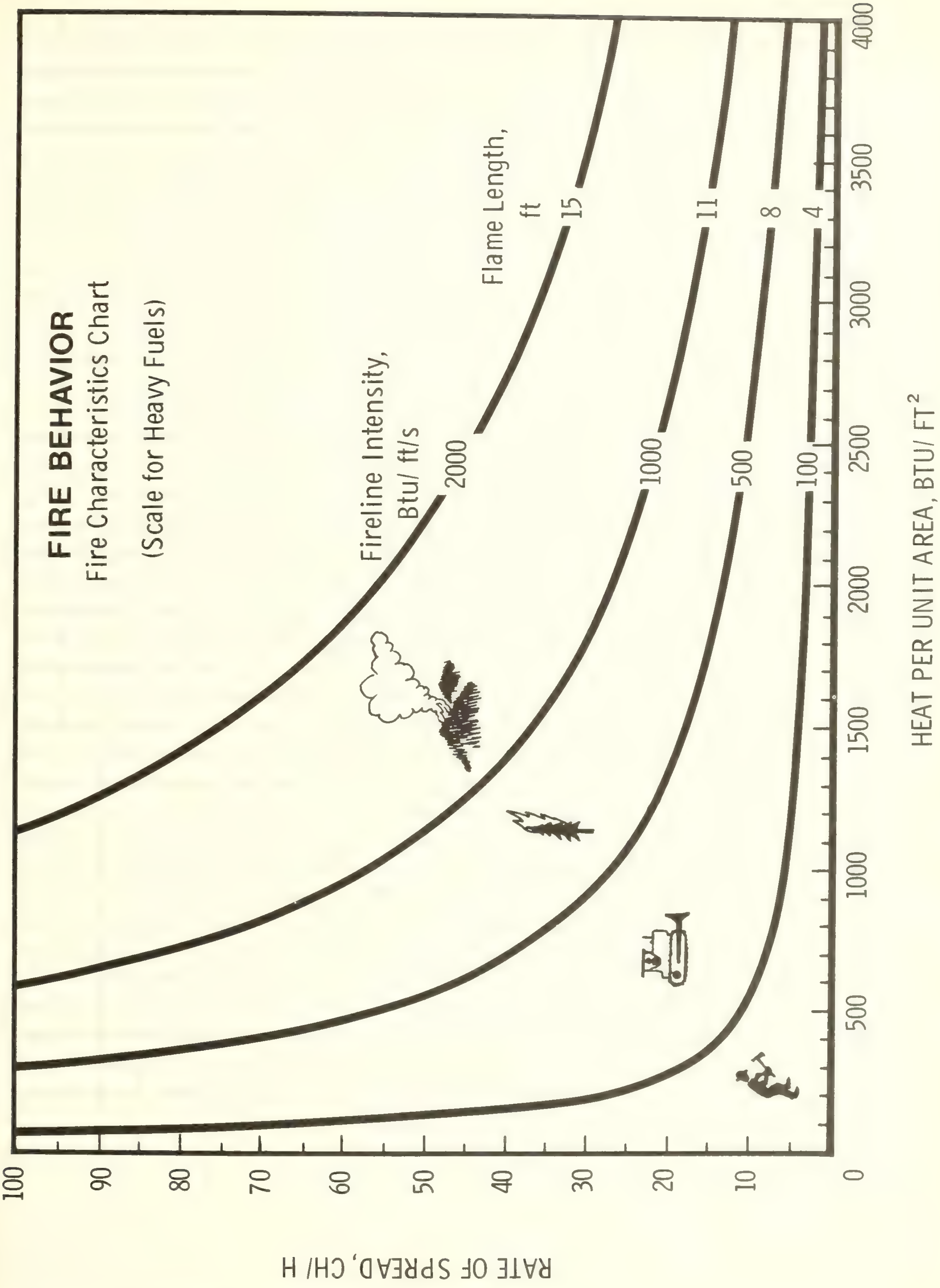


Figure IV-2.—Fire behavior fire characteristics chart scaled for heavy fuels.

FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)

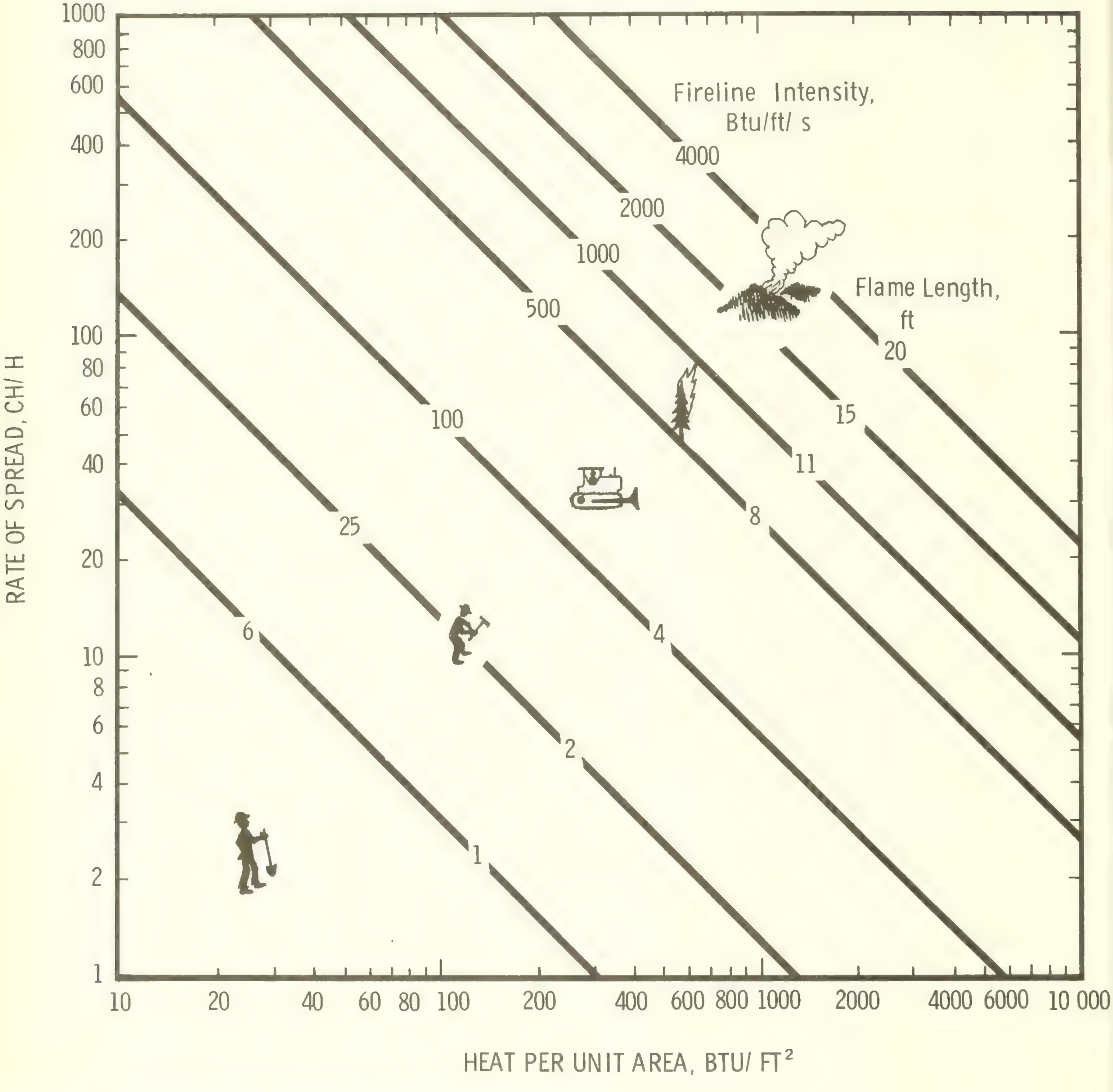


Figure IV-3.—Fire behavior fire characteristics chart with logarithmic scale.

Fire Growth From A Point Source

APPLICABILITY OF POINT SOURCE METHOD

When viewed from above, during initial growth a fire is elliptical or egg-shaped. Strong winds or steep slopes can elongate the shape, but it remains surprisingly consistent until fuels or the wind change. Anderson (1983) developed equations for predicting fire shapes as influenced by the effective windspeed from data taken by Fons.[1] Fire shapes calculated from these equations are shown in figure IV–4. Anderson's equations, which were reported by Albini (1976), will predict both the perimeter and the area of a fire starting from a point source such as a lightning strike or a firebrand. When a fire has become large enough so that there is no interaction between the head and rear of the fire, the fire model can be used to estimate the major spread distance. The spread distance is the product of the projection time and the rate of spread. In figure IV–4, the calculated spread distance "D" is from the point of origin to the furthest advance at the narrow end of the ellipse. If the TI–59 is being used to calculate fire behavior, the spread distance, the perimeter, and the area of the fire based on this elliptical shape can all be obtained as direct outputs. The spread distance and perimeter are expressed in chains. The area is expressed in acres. The effective windspeed is stored internally and is not available for display on the calculator.

For application of the point source method when fire is on a slope, it is assumed that any wind on the fire is blowing within ±30° of directly upslope.

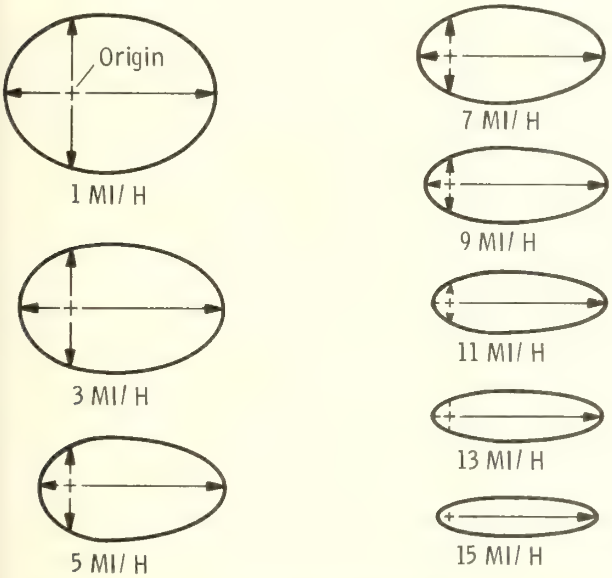


Figure IV-4.—Fire shapes associated with effective windspeeds.

[1]Fons, Wallace L. Forest Fuels Progress Report No. 6, RW-Cal, Fire Behavior, Forest Fuels. Calif. For. and Range Exp. Stn., May 20, 1940. Report on file (unpublished).

Manual Calculation Procedures

If the TI–59 is not available, the perimeter and area can be determined from a pair of tables developed for the S–390 Fire Behavior Course.[2] To use the tables you will need the effective windspeed from line 18 of the fire behavior worksheet and the spread distance from line 23. As a reminder, spread distance is the rate of spread from line 19 multiplied by the projection time from line 15.

To obtain the perimeter, enter the top of table IV–2 with the effective windspeed and go down the column until you reach the row adjacent to the spread distance. Interpolate between columns and rows as necessary.

Example:

R = 20 ch/h
t = 1 hour
D = 20 chains
Effective windspeed = 9 mi/h
From table IV–2, perimeter = 52 chains

Area is obtained by identical procedures from table IV–3. For the above example: area = 14 acres.

Exercise 1

Given: A spot fire occurs outside a prescribed burn at 1200, the rate of spread is predicted to be 15 ch/h. Effective midflame windspeed is 8 mi/h. A patrol with hand tools and backpack pumps will arrive by 1230. A tractor can be on the fire by 1330.

Solve: The fire perimeter and area when
- the patrol arrives.
- the tractor arrives (hand crew ineffective on the fire front).

Solution:

Time for hand crew to arrive is 1/2 hour.
Spread distance at that time will be 7–1/2 chains.
Perimeter will be about 20 chains.
Area will be about 2 acres.
Note that it was necessary to interpolate between numbers in tables IV–2 and IV–3.
Time for tractor to arrive is 1 hour.
Spread distance at that time will be 15 chains.
Perimeter will be about 40 chains.
Area will be about 9 acres.

[2]National Wildfire Coordinating Group's S–390 Fire Behavior Course. Produced by Boise Interagency Fire Center, Joe Duft and Jerry Williams, cochairmen of course development.

Table IV-2.— Perimeter estimations for point source fires (from S-390 course material)

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Chains									
1	3	3	3	2	2	2	2	2	2	2
2	7	6	6	5	5	5	4	4	4	4
3	11	10	9	8	7	7	7	7	6	6
4	15	13	12	11	10	10	9	9	9	9
5	19	17	15	14	13	12	12	11	11	11
6	23	20	18	16	15	15	14	14	13	13
7	27	23	21	19	18	17	17	16	16	16
8	31	27	24	22	21	20	19	19	18	18
9	35	30	27	25	23	22	21	21	20	20
10	39	34	30	28	26	25	24	23	23	23
11	43	37	33	31	29	27	26	26	25	25
12	47	41	36	33	31	30	29	28	27	27
13	50	44	39	36	34	32	31	30	30	29
14	54	47	43	39	37	35	34	33	32	32
15	58	51	46	42	39	37	36	35	34	34
16	62	54	49	45	42	40	39	38	37	36
17	66	58	52	48	45	42	41	40	39	39
18	70	61	55	50	47	45	43	42	41	41
19	74	65	58	53	50	47	46	45	44	43
20	78	68	61	56	52	50	48	47	46	46
21	82	71	64	59	55	53	51	49	48	48
22	86	75	67	62	58	55	53	52	51	50
23	90	78	70	64	60	58	56	54	53	52
24	94	82	73	67	63	60	58	57	55	55
25	98	85	76	70	66	63	60	59	58	57
26	101	88	79	73	68	65	63	61	60	59
28	109	95	86	79	74	70	68	66	65	64
30	117	102	92	84	79	75	73	71	69	69
32	125	109	98	90	84	80	78	76	74	73
34	133	116	104	96	90	85	82	80	79	78
36	141	123	110	101	95	90	87	85	83	82
38	148	130	116	107	100	95	92	90	88	87
40	156	136	122	112	105	101	97	95	93	92
42	164	143	129	118	111	106	102	99	97	96
44	172	150	135	124	116	111	107	104	102	101
46	180	157	141	129	121	116	112	109	107	105
48	188	164	147	135	127	121	117	114	111	110
50	196	171	153	141	132	126	121	118	116	115
52	203	177	159	146	137	131	126	123	121	119
54	211	184	165	152	143	136	131	128	125	124
56	219	191	172	158	148	141	136	133	130	128
58	227	198	178	163	153	146	141	137	135	133
60	235	205	184	169	158	151	146	142	139	138
62	243	212	190	175	164	156	151	147	144	142
64	250	219	196	180	169	161	156	152	149	147
66	258	225	202	186	174	166	160	156	153	151
68	266	232	208	192	180	171	165	161	158	156
70	274	239	215	197	185	176	170	166	163	161

Table IV-2.—(con).

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Chains									
72	282	246	221	203	190	181	175	171	167	165
74	290	253	227	209	196	186	180	175	172	170
76	297	260	233	214	201	191	185	180	177	174
78	305	266	239	220	206	197	190	185	181	179
80	313	273	245	225	211	202	195	190	186	184
82	321	280	251	231	217	207	199	194	191	188
84	329	287	258	237	222	212	204	199	195	193
86	337	294	264	242	227	217	209	204	200	197
88	344	301	270	248	233	222	214	209	205	202
90	352	308	276	254	238	227	219	213	209	207
92	360	314	282	259	243	232	224	218	214	211
94	368	321	288	255	249	237	229	223	219	216
96	376	238	294	271	254	242	234	228	223	220
98	384	335	301	276	259	247	239	232	228	225
100	392	342	307	282	264	252	243	237	233	230
105	411	359	322	296	278	265	256	249	244	241
110	431	376	337	310	291	277	268	261	256	253
115	450	393	353	324	304	290	280	273	268	264
120	470	410	368	338	317	303	295	285	279	276
125	490	427	383	353	331	315	304	297	291	287
130	509	444	399	367	344	328	317	308	303	299
135	529	462	414	381	357	341	329	320	314	310
140	548	479	430	395	370	353	341	332	326	322
145	568	496	445	409	384	366	353	344	338	333
150	558	513	460	423	397	378	365	356	349	345
155	607	530	476	437	410	391	378	368	361	356
160	627	547	491	451	423	404	390	380	373	368
165	646	564	506	466	437	416	402	392	384	379
170	666	581	522	480	450	429	414	404	396	391
175	686	599	537	494	363	442	426	415	408	402
180	705	616	552	508	476	454	439	427	419	414
185	725	633	568	522	490	467	451	439	431	425
190	744	650	583	536	503	479	463	451	443	437
195	764	667	599	550	516	492	475	463	454	448
200	784	684	614	564	529	505	487	475	466	460
210	823	718	645	593	556	530	512	499	489	483
220	862	753	675	621	582	555	536	522	513	506
230	901	787	706	649	609	581	560	546	536	529
240	940	821	737	677	635	606	585	570	559	552
250	980	855	767	706	662	631	609	594	583	575
260	1019	889	798	734	688	656	634	617	606	598
270	1058	924	829	762	715	682	658	641	629	621
280	1097	958	860	790	741	707	682	665	653	644
290	1136	992	890	819	768	732	707	689	676	667
300	1176	1026	921	847	794	757	731	713	699	690

NOTE: Interpolations will become less accurate at the lower end of this table due to the greater spans between spread distance values and the nonlinear equations used to produce the table. Your interpolated values may differ some what from those given by the TI-59 calculator with CROM.

Table IV-3.— Area estimations for point source fires (from S-390 course material)

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Acres									
1	.1	.1	.1							
2	.5	.3	.3	.3	.2	.1	.1	.1	.1	
3	1.1	.8	.6	.4	.3	.3	.2	.2	.1	.1
4	1.9	1.4	1	.8	.6	.5	.4	.3	.2	.2
5	2	2	1.6	1.2	.9	.7	.6	.5	.4	.3
6	4	3	2	1.7	1.3	1.1	.8	.7	.5	.4
7	5	4	3	2	1.8	1.4	1.1	.9	.7	.6
8	7	5	4	3	2	1.9	1.5	1.2	.9	.7
9	9	6	5	3	3	2	1.9	1.5	1.2	.9
10	11	8	6	4	3	2	2	1.8	1.5	1.2
11	14	10	7	5	4	3	2	2	1.8	1.4
12	17	12	9	6	5	4	3	2	2	1.7
13	20	14	10	8	6	4	3	3	2	2
14	23	16	12	9	7	5	4	3	2	2
15	26	19	14	10	8	6	5	4	3	2
16	30	21	16	12	9	7	5	4	3	2
17	34	24	18	14	10	8	6	5	4	3
18	38	27	20	15	12	9	7	5	4	3
19	42	30	23	17	13	10	8	6	5	4
20	47	34	25	19	14	11	9	7	5	4
21	52	37	28	21	16	12	10	8	6	5
22	57	41	30	23	18	14	11	8	7	5
23	62	45	33	25	19	15	12	9	7	6
24	68	49	36	27	21	16	13	10	8	6
25	74	53	39	30	23	18	14	11	9	7
26	80	57	43	32	25	19	15	12	9	7
28	92	67	50	38	29	22	18	14	11	9
30	106	77	57	43	33	26	20	16	13	10
32	121	87	65	49	38	29	23	18	14	11
34	137	99	73	56	43	33	26	21	16	13
36	153	111	82	62	48	37	29	23	18	14
38	171	123	92	70	54	42	33	26	20	16
40	189	137	102	77	59	46	36	29	23	18
42	209	151	112	85	66	51	40	32	25	20
44	229	166	123	93	72	56	44	35	28	22
46	250	181	135	102	79	61	48	38	30	24
48	273	197	147	111	86	67	53	42	33	26
50	296	214	159	121	93	73	57	45	36	28
52	320	231	172	131	101	79	62	49	39	31
54	345	250	186	141	109	85	67	53	42	33
56	371	269	200	152	117	91	72	57	45	36
58	398	288	214	163	125	98	77	61	48	38
60	426	308	229	174	134	105	82	65	52	41
62	455	329	245	186	143	112	88	70	55	44
64	485	351	261	198	153	119	94	74	59	47
66	516	373	277	211	163	127	100	79	63	50
68	548	396	295	224	173	135	106	84	67	53
70	580	420	312	237	183	143	112	89	71	56

Table IV-3.—(con).

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Acres									
72	614	444	330	251	194	151	119	94	75	59
74	649	469	349	265	205	160	126	99	79	63
76	684	495	368	280	216	169	133	105	83	66
78	721	521	388	295	227	178	140	111	88	70
80	758	549	408	310	239	187	147	116	92	73
82	797	576	429	326	251	196	154	122	97	77
84	836	605	450	342	264	206	162	128	102	81
86	876	634	471	358	276	216	170	135	107	85
88	917	664	494	375	290	226	178	141	112	89
90	960	694	516	392	303	237	186	147	117	93
92	1003	726	540	410	316	247	195	154	122	97
94	1047	758	563	428	330	258	203	161	128	102
96	1092	790	588	446	345	269	212	168	133	106
98	1138	823	612	465	359	281	221	175	139	110
100	1185	857	638	484	374	292	230	182	145	115
105	1306	945	703	534	412	322	254	201	159	127
110	1434	1038	772	586	453	354	278	220	175	139
115	1567	1134	843	641	495	386	304	241	191	152
120	1706	1235	918	698	539	421	331	262	208	166
125	1852	1340	997	757	585	457	360	285	226	180
130	2003	1449	1078	819	632	494	389	308	245	195
135	2160	1563	1163	883	682	533	420	332	264	210
140	2323	1681	1250	950	734	573	451	357	284	226
145	2492	1803	1341	1019	787	615	484	383	304	242
150	2667	1930	1435	1091	842	658	518	410	326	259
155	2847	2061	1533	1165	899	703	553	438	348	277
160	3034	2196	1633	1241	958	749	590	467	371	295
165	3227	2335	1737	1320	1019	796	627	496	394	314
170	3425	2479	1844	1401	1082	845	666	527	419	333
175	3630	2627	1954	1485	1146	896	705	559	444	353
180	3840	2779	2067	1571	1213	948	746	591	470	374
185	4057	2936	2184	1659	1281	1001	788	624	496	395
190	4279	3097	2303	1750	1352	1056	832	658	523	417
195	4507	3262	2426	1844	1424	1112	876	694	551	439
200	4741	3431	2552	1939	1498	1170	921	730	580	462
210	5227	3783	2814	2138	1651	1290	1016	804	639	509
220	5737	4152	3088	2347	1812	1416	1115	883	702	559
230	6720	4538	3375	2565	1981	1547	1219	965	767	611
240	6827	4941	3675	2793	2157	1685	1327	1051	835	665
250	7408	5362	3988	3031	2340	1828	1440	1140	906	722
260	8013	5799	4313	3278	2531	1978	1558	1233	980	780
270	8641	6254	4652	3535	2730	2133	1680	1330	1057	842
280	9293	6726	5003	3802	2936	2294	1807	1431	1137	905
290	9969	7215	5366	4078	3149	2460	1938	1535	1219	971
300	10668	7721	5743	4364	3370	2633	2074	1642	1305	1039

NOTE: Interpolations will become less accurate at the lower end of this table due to the greater spans between spread distance values and the nonlinear equations used to produce the table. Your interpolated values may differ some what from those given by the TI-59 calculator with CROM.

Exercise 2

Given: A fire is started accidentally in a large clearcut in medium logging slash (fuel model 12). The fire starts at 4 p.m. On site the 20-ft windspeed is 12 mi/h, temperature 63° F, relative humidity 31 percent, skies are clear. The area is level. The date is October 12.

Solve:
- Fuel moisture and midflame windspeed using appropriate tables.
- Rate of spread, flame length, and fireline intensity using nomograms.
- Area and perimeter of fire at 1700 hours.
- Plot fire behavior outputs on a fire characteristics chart.

Solution is shown on accompanying worksheets.

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	Exercise 2			
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	63			
d. Relative humidity, %	31			
e. Reference fuel moisture, % (from table A)	5			
f. Month	Oct			
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	1600			
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	Flat			
k. Slope	0			
l. Fuel moisture correction, % (from table B, C, or D)	2			
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	7			
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Point Source Ex. 2 FIRE BEHAVIOR OFFICER ____

DATE ____ TIME ____

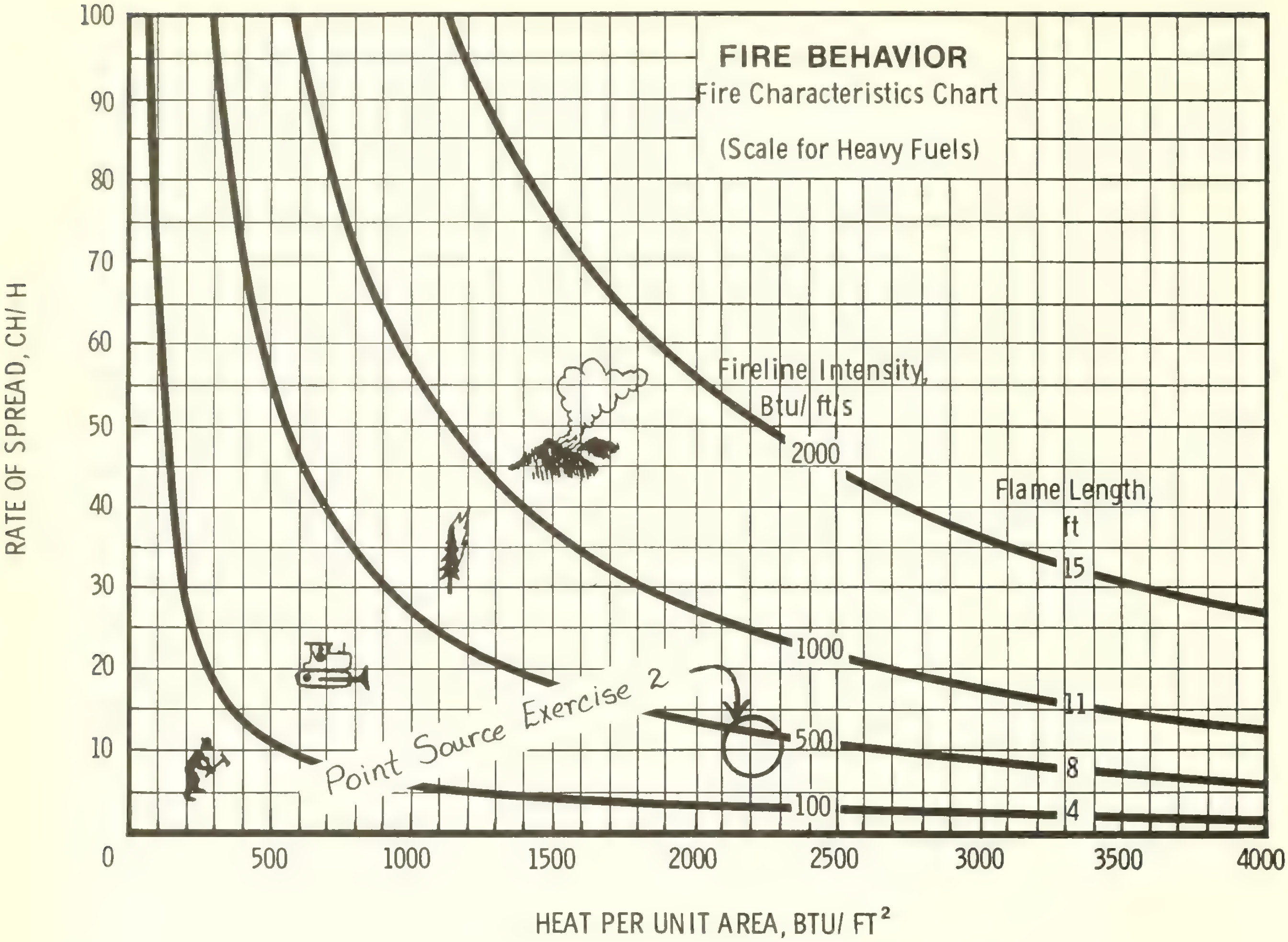
PROJ. PERIOD DATE ____ PROJ. TIME FROM ____ to ____

INPUT DATA — Data sheet entries for nomogram solution.

								TI-59 Reg. No.
1	Projection point			1				
2	Fuel model proportion, %			100				
3	Fuel model			12				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE					60
5	Dry bulb temperature, °F		DB					61
6	Relative humidity, %		RH					62
7	1 H TL FM, %	from fuel moisture tables	1H	7				28
8	10 H TL FM, %		10H	–				63
9	100 H TL FM, %		100H	–				30
10	Live fuel moisture, %		LIVE	–				33
11	20-foot windspeed, mi/h			(12)	( )	( )	( )	
12	Wind adjustment factor			(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	5				79
14	Maximum slope, %		PCT S	0				80
15	Projection time, h		PT	1				81
16	Map scale, in/mi		MS					82
17	Map conversion factor, in/ch			–				
18	Effective windspeed, mi/h			5				

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	12				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	2200				90
21	Fireline intensity, Btu/ft/s	[B]	INT	400				53
22	Flame length, ft	[R/S]	FL	7				54
23	Spread distance, ch	[C]	SD	12				42
24	Map distance, in	[R/S]	MD	–				43
25	Perimeter, ch	[D]	PER	36				40
26	Area, acres	[R/S]	AREA	9				89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52



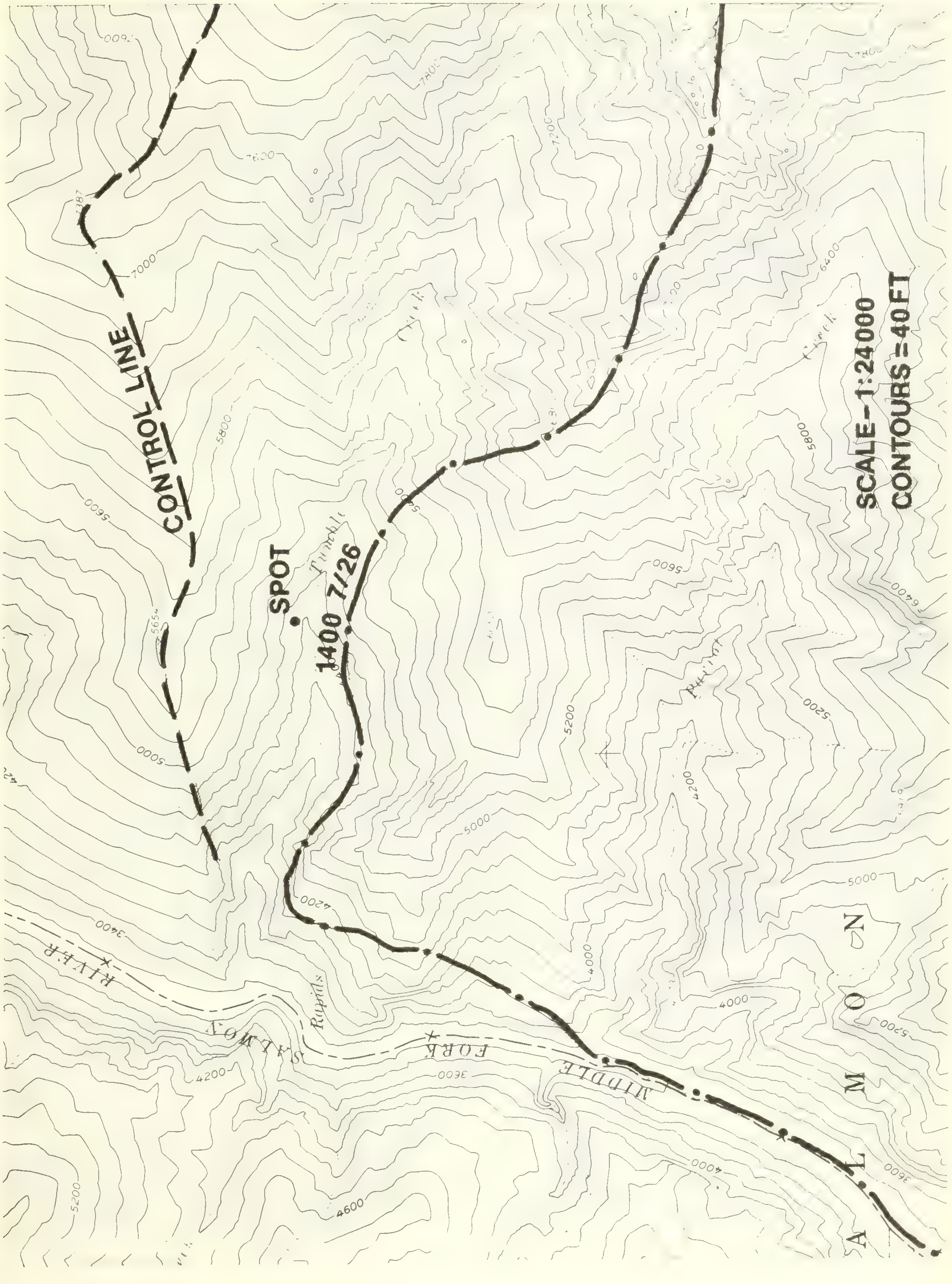
Spot Fire Exercise

(Ship Island Fire, Salmon National Forest, Idaho; July 1979)

Given: A fire is detected on July 25 at 1400 hours by the aerial observer. The location of the fire is shown on the attached map. The attached spot weather forecast was received for the fire area. Use the following inputs:

- Live fuel moisture 100%
- Fuels: model 1 = 20% of area covered
  model 5 = 80% of area covered
- Slope – calculate from map
- Dead fuel moisture – use tables
- Weather inputs from spot forecast.

Problem: What is the potential size of this fire in 1/2 hour? Solution is shown on accompanying worksheets.


CONTROL LINE
SPOT
1400 7/26
SCALE—1:24000
CONTOURS=40FT
MIDDLE
FORK
SALMON
RIVER
Rapids

FIRE WEATHER SPECIAL FORECAST REQUEST

(See reverse for instructions)

I. REQUESTING AGENCY WILL FURNISH:

1. NAME OF FIRE OR OTHER PROJECT	2. CONTROL AGENCY	3. REQUEST MADE TIME†	DATE
Ship Island	USFS	0630	7/25/79

4. LOCATION (By ¼ Sec Sec Twp Range)	5. DRAINAGE NAME	6. EXPOSURE (NE. E. SE. etc.)
T21N, R14E, Sec. 1-2, 11-12	Tumble Creek	S

7. SIZE OF PROJECT (Acres)*	8. ELEVATION* TOP	BOTTOM	9. FUEL TYPE	10. PROJECT ON:
2600	8500	3400	Douglas-fir, brush	☒ GROUND / CROWNING

11. WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS *(See example on reverse)*

PLACE	ELEVATION	OB TIME†	WIND DIR.-VEL. 20 FT.	WIND DIR.-VEL. EYE LEVEL	TEMP. DRY	TEMP. WET	‡(Leave blank) RH	‡(Leave blank) DP	REMARKS (Indicate rain, thunderstorms, etc. Also wind condition and 10ths of cloud cover)
Stoddard L.O.	7540	0630	SSW-15		55	41			Yesterday max. temp. on fire (4800') 87°; min. RH 16%

12. SEND FORECAST TO:	PLACE	VIA	ATTN: (Name, if applicable)
	Stoddard L.O.	Radio	Rinehart

II. FIRE WEATHER FORECASTER WILL FURNISH:

13. FORECAST AND OUTLOOK **TIME† AND DATE:** ________

(SPECIFY WIND - 20 FOOT OR EYE LEVEL)

SPOT WEATHER FORECAST FOR SHIP ISLAND FIRE ISSUED AT 0700 MDT WEDNESDAY JULY 25 1979

DISCUSSION . . . WINDS ALOFT FROM THE SOUTHWEST TO PERSIST FOR THE NEXT COUPLE OF DAYS. SOME ALTO CUMULUS CLOUDS SOUTHWEST OF THE FIRE AREA NOT LIKELY TO LEAD TO ANY SHOWER OR THUNDERSHOWER ACTIVITY.

TODAY . . . SUNNY. MAX TEMP 90 TO 95 LOWER ELEVATIONS AND 60 TO 65 IN THE HIGHER ELEVATIONS. MIN REL HUM 10 TO 15 PERCENT. WINDS DECREASING SLIGHTLY TO SOUTHWEST 5 TO 10 MI/H REST OF THE DAY BUT OCCASIONAL HIGHER GUSTS TO 20 MI/H AT THE HIGHER ELEVATIONS. GOOD SMOKE DISPERSAL.

TONIGHT . . . FAIR. MIN TEMP IN THE 40'S LOWER ELEVATIONS AND 50'S HIGHER ELEVATIONS. MAX REL HUM 35 TO 45 PERCENT. SURFACE TEMPERATURE INVERSION FORMING. WINDS SOUTHWEST 10 TO 15 RIDGES AND NEAR CALM TO EAST TO SOUTHEAST 4 TO 8 MI/H LOWER ELEVATIONS.

THURSDAY . . . CONTINUED SUNNY WITH LITTLE CHANGE IN TEMP REL HUM AND WIND.

NAME OF FIRE WEATHER FORECASTER	FIRE WEATHER OFFICE

III. REQUESTING AGENCY WILL COMPLETE UPON RECEIPT OF FORECAST

IV. FORECAST RECEIVED:	TIME†	DATE	NAME
	0730	7/25	GEORGE RINEHART

Explanation of Symbols:

- † Use 24-hour clock to indicate time. Example: 10:15 p.m. = 2215; 10:15 a.m. = 1015.
- * For concentrations (as groups of lightning fires) specify "Concentration"; then give number of fires and size of largest. If concentrations are in more than one drainage, request special forecast for each drainage.
- ‡ No entry necessary. To be computed by the Fire Weather Forecaster.

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	1			
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	95			
d. Relative humidity, %	10			
e. Reference fuel moisture, % (from table A)	2			
f. Month	July			
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	1400			
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	SW			
k. Slope	80 %			
l. Fuel moisture correction, % (from table B, C, or D)	1			
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	3			
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Ship Island FIRE BEHAVIOR OFFICER George Rinehart

DATE July 24, 1979 TIME 1400

PROJ. PERIOD DATE July 24, 1979 PROJ. TIME FROM 1400 to 1430

INPUT DATA								TI-59 Reg. No.
1	Projection point			1	1			
2	Fuel model proportion, %			20	80			
3	Fuel model			1	5			
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0				60
5	Dry bulb temperature, °F		DB	95				61
6	Relative humidity, %		RH	10				62
7	1 H TL FM, %		1H	3	3			28
8	10 H TL FM, %		10H	-	4			63
9	100 H TL FM, %		100H	-	5			30
10	Live fuel moisture, %		LIVE	-	100			33
11	20-foot windspeed, mi/h			(12)	( )	( )	( )	
12	Wind adjustment factor			(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	5				79
14	Maximum slope, %		PCT S	80	Ditto			80
15	Projection time, h		PT	.5				81
16	Map scale, in/mi		MS	2.64				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

$.2 \times 260 + .8 \times 55 = 96 \rightarrow \boxed{STO}\ 88$

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	260	55	96		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	108	735			90
21	Fireline intensity, Btu/ft/s	[B]	INT	490	735			53
22	Flame length, ft	[R/S]	FL	8	9			54
23	Spread distance, ch	[C]	SD			48		42
24	Map distance, in	[R/S]	MD			1.6		43
25	Perimeter, ch	[D]	PER			130		40
26	Area, acres	[R/S]	AREA			96		89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

Estimating Spread From a Line of Fire

CONCEPT

When a fire becomes large or irregular in shape, the point source calculations shown in the preceding section are no longer satisfactory for determining its growth. Some sectors of the fire may be under control, while other sectors may be burning into fuels with potential for rapid rate of spread. Shifting winds and irregular terrain can cause irregular burning along the line. On a project fire, the fire's growth from an existing fireline will usually be plotted for briefing the fire planning staff and the fire suppression team. This is a difficult problem, and it requires more encompassing techniques[3] than described up to here in the manual. The concept was described in chapter I in the section labeled "Fire Prediction Process." That section should be carefully reviewed before proceeding.

Close attention must be given to the change in burning conditions with time of day. Fires can become dormant during the night and flare up again as burning conditions improve. Success of these procedures demands that weather forecasts be applied to the time of the day for which they are applicable.

To fully understand these methods, one must complete the exercises at the end of this section. Some of the exercises were designed to stress a technique; others are taken from real fire situations.

It is important to remember that the numbers generated in the calculations are not the final answer. They must be interpreted in terms that are meaningful to members of the fire suppression team and displayed on a map illustrating fire growth.

The depth and detail that are applied to this problem depend upon many factors:

1. The time available to make the fire assessment.
2. The stage of fire development and control actions.
3. Size of the fire.
4. Availability of scouting information.
5. Availability of weather forecasts.
6. Irregularity of the terrain.
7. How well the fuel model and computational methods match the actual fuels and fire behavior.

It may seem that, in many cases, the answers to the considerations mentioned above will be rather negative. Nevertheless, the method has been found to work well when the user has gained proficiency in the technique and in the ability to interpret conditions along the firelines.

PROCEDURES

Preparation

The following material will aid in predicting and presenting fire behavior assessments:

- Topographic map of the fire area with a resolution of at least 2 inches per mile.
- Tablets of Fire Behavior Worksheets.
- Transparent ruler calibrated in inches and tenths of inches.
- Tracing paper.
- Colored felt-tip pens.
- Charts and tables for determining inputs.
- Fire Characteristics Charts.
- Nomograms or TI–59 with fire behavior CROM.

Lay out the known fireline location on a topographic map large enough to accommodate the growth of the fire. Indicate on the map the time that the fire perimeter was located. If you do not have extra maps, use tracing paper overlays for plotting winds and the expected growth of the fire. Obtain a fuel map or draw one with the aid of local help, aerial reconnaissance, or scouting reports. Indicate the general overstory condition and the surface vegetation on the map. Classify the areas in terms of fuel models to the extent possible. These choices may have to be improved as the fire is observed and the fuel stratum carrying the fire is identified.

Determine Projection Time

Specific time periods, when conditions are expected to be reasonably constant, should be designated for making projections. Choice of projection times can help alleviate problems of nonuniform or changing conditions. For example, weather can be broken into 2- to 4-hour periods such as late morning, early afternoon, and late afternoon, when temperature, humidity, and windspeed can be expected to be reasonably uniform, yet different enough to justify a new calculation. Be alert to forecasted changes in windspeed. Be sure to break and restart fire projections at these times.

Abrupt changes in fuels are commonly encountered. This is accentuated in mountainous or steep terrain where the fire can spread up a slope from grass cover into shrub or timber cover. The exact time required to traverse one fuel type is not known. It can be approximated by dividing the expected rate of spread into the width of the fuel strip. As experience is gained, estimates of traverse times can be made. One or two iterations may be necessary to designate a projection time that approximates the time that the fire is in a single fuel type.

Change in slope often occurs in the same places that vegetation or fuel types change. Projection times are usually not based upon expected times for the fire to burn onto a different slope although they could be.

The exercises will illustrate these points.

Select Projection Points

Before selecting the points at which the projections will be made, proceed through the first few steps of the wind estimation process and estimate the local 20-ft winds around the fire perimeter. Select a few points on the fire perimeter that are the most likely to be the origin of significant fire growth. Three points should be adequate for all but very large fires. Often one or two points are adequate for quick assessment during early stages or when most of the fireline is secure. Locations on the downwind side of the fire, with predicted strong local winds, or on the uphill side of a fire on a steep slope, are the usual choices. Fire control actions and areas of very flammable fuel ahead of the fire will also influence the choice of projection points. In some cases the person responsible for fire suppression will want to know the probability of a fire reaching threatened natural or manmade features. Your experience in fire behavior must be used in the choice of projection points. Scouting the fire on the ground or in the air can greatly aid this process. If you cannot scout the fire, learn what the fire has done in previous burning periods, both from documentation (maps) and witnesses.

[3]The author developed the technique for the fire behavior officer course in 1976, and has modified it based on experience.

Determine Input Data

Identify each projection point on the map with a small number with a circle around it. Place the same number at the head of a column on a fire behavior worksheet. Determine the inputs at each projection point as described in chapter II and enter them in the appropriate column on the fire behavior worksheet.

Determine Spread Distance

If the fire is traveling upslope and the wind is blowing directly upslope or within 30° of maximum slope, data on the fire behavior worksheet may be used according to the instructions up to this point. An arrow equal in length to the map distance should be drawn on the map from the projection point directly up the steepest slope, as shown at projection point 1 in figure IV-5. This arrow or vector represents the expected spread distance of the fire from this point during the projection time. There will be cases when the fire spread direction and wind do not cooperate so nicely and it is necessary to amend the procedures to get a realistic fire growth projection.

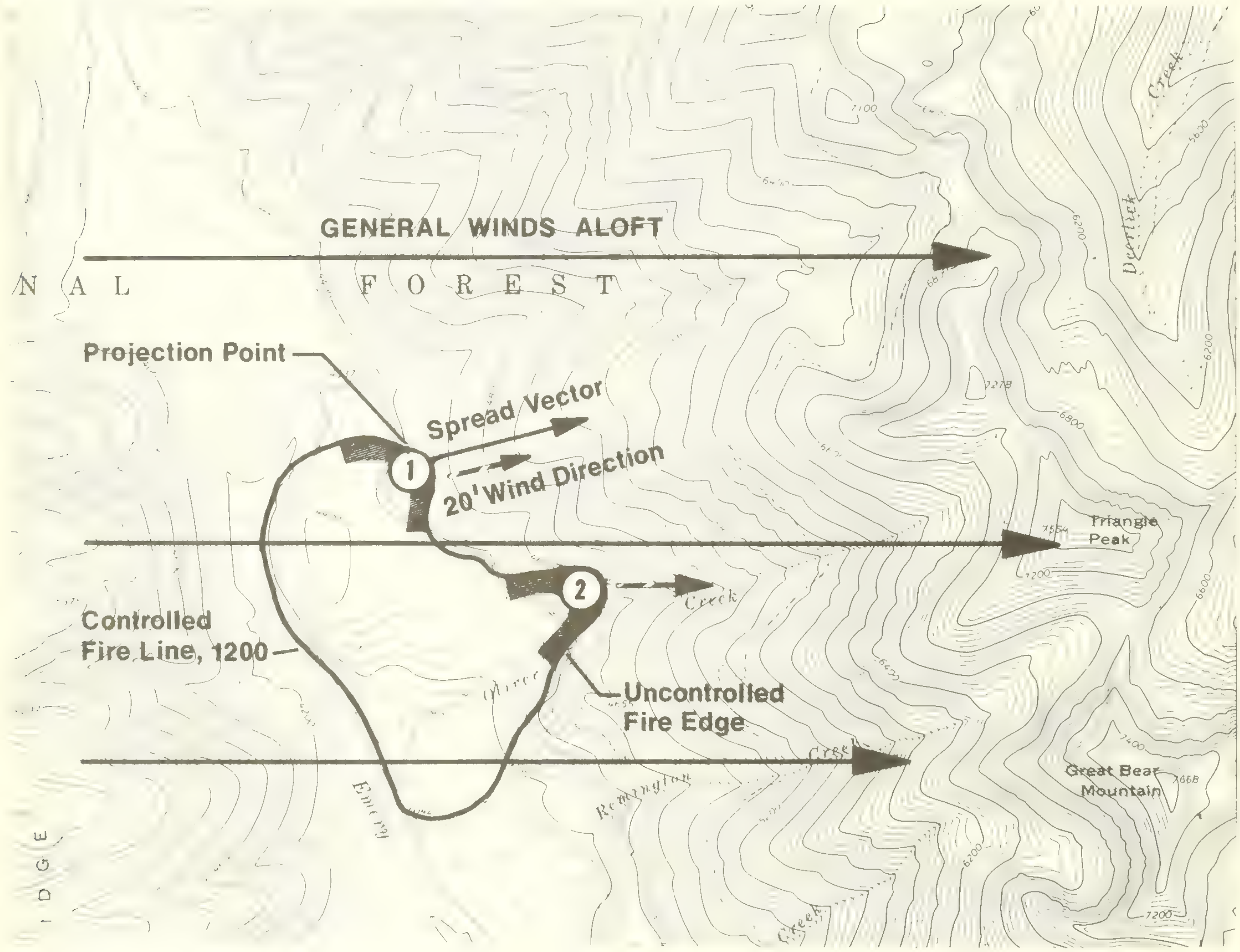


Figure IV-5.—Fire spread vector with wind direction up maximum slope.

Cross-Slope Fire Spread

If the wind is not blowing directly upslope or within ± 30° of upslope, the effect of wind and slope are determined separately and then combined. This is done by the use of vectors on the map.

Step 1.—Use two columns on the fire behavior worksheet. All inputs will be the same for both columns except the midflame windspeed and maximum slope. In the first column enter the midflame windspeed on line 13 as determined from the wind procedure for that projection point and enter zero for maximum slope on line 14. In the second column, reverse the process, with a zero entry for the midflame windspeed, but enter the actual value of maximum slope that lies above the projection point.

Step 2.—Make the calculations necessary to determine map distance. Record the first six outputs, lines 19 through 24 for each column on the worksheet. If the TI-59 is being used, it is only necessary to enter the data once, but change the wind and slope data before the second calculation.

Step 3.—The two map distances just calculated indicate the separate influences of wind and slope on the fire. The combined influence and estimated spread of the fire are found with vectors or arrows on the map. Draw a wind vector on the map from the projection point in the direction of the local 20-ft wind equal to the map distance in the first column. Similarly, draw a slope vector the length of the map distance in the second column directly up the maximum slope as shown in figure IV-6.

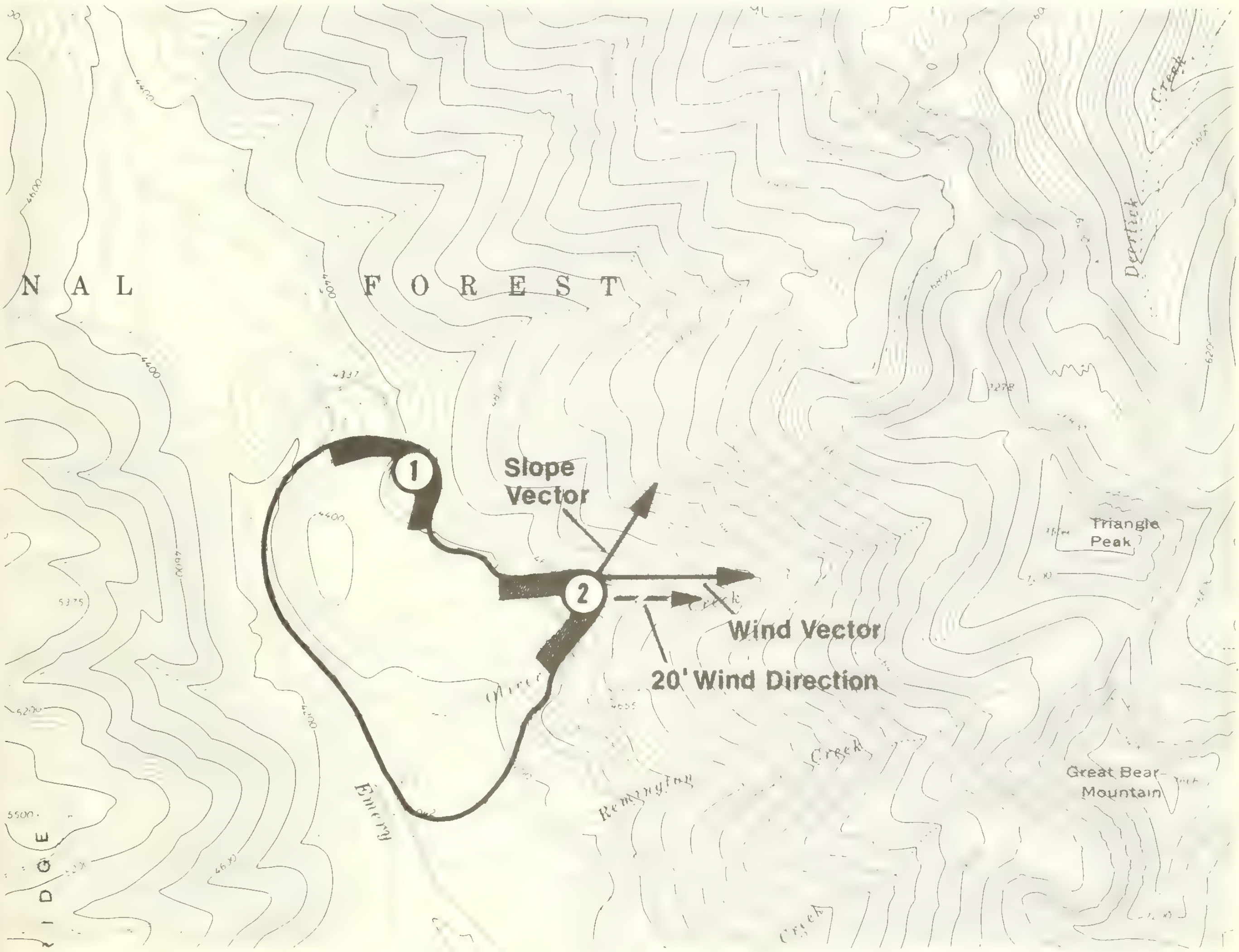


Figure IV-6.—Wind and slope vectors.

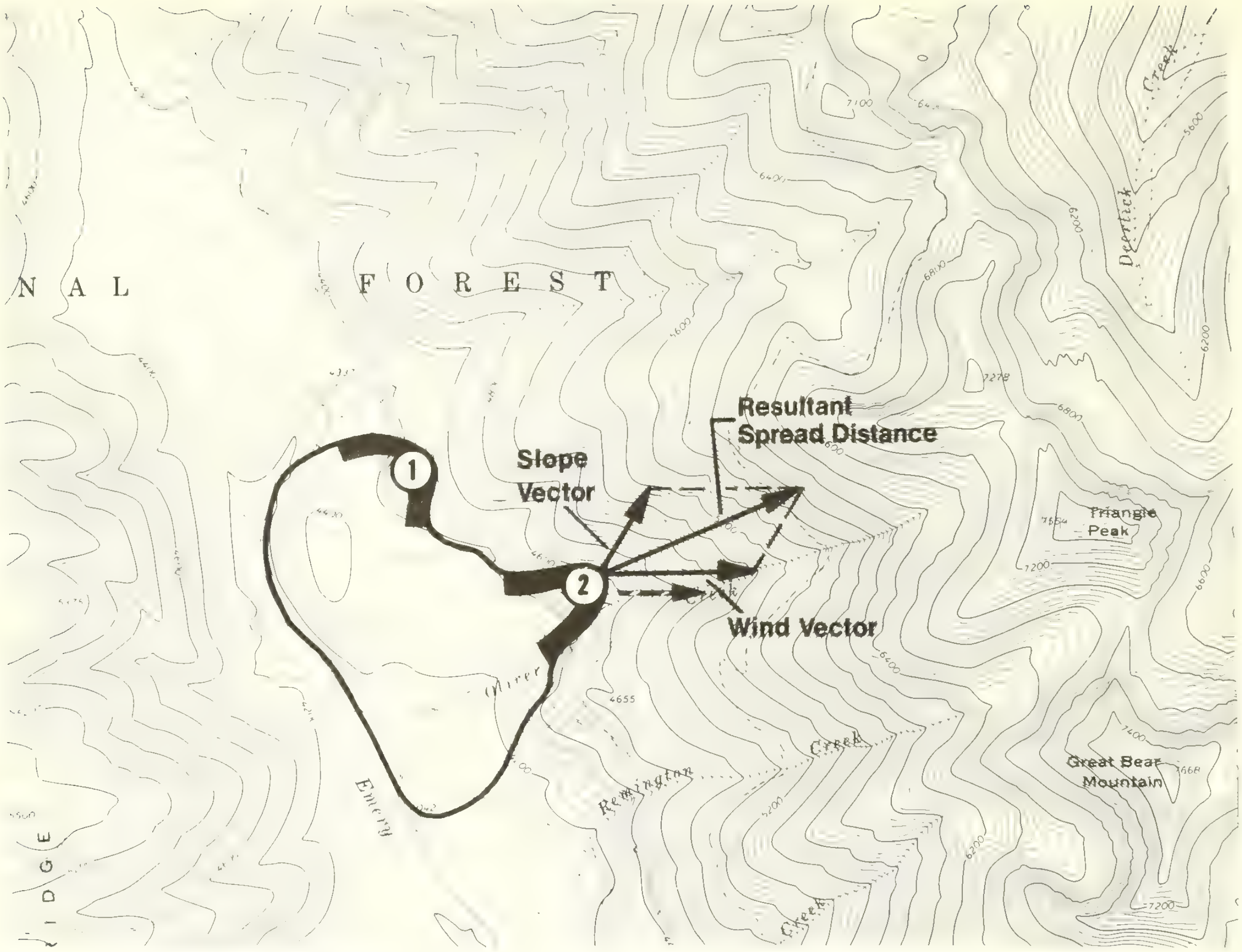


Figure IV-7.—Resultant fire spread vector.

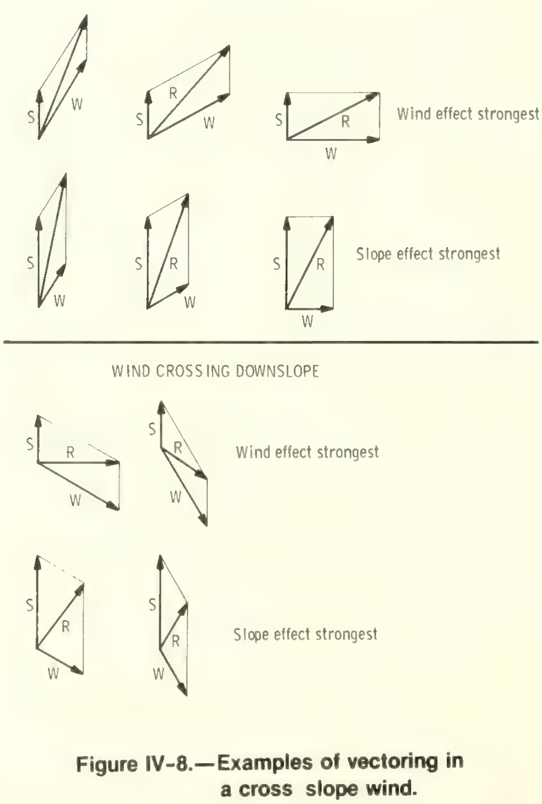


Figure IV-8.—Examples of vectoring in a cross slope wind.

Step 4.—The total distance the fire will spread from the projection point is represented by the resultant of the wind vector and the slope vector. The resultant is found by constructing a parallelogram using the two vectors as the sides as shown in figure IV-7. A parallelogram is constructed with opposite sides parallel and equal in length. The resultant or maximum spread distance is found by drawing an arrow across the parallelogram from the projection point to the opposite corner, as shown in figure IV-7. Complete these four steps for each projection point that has a cross-slope wind.

The same technique is used for winds crossing downslope, but the diagrams may look quite different, depending on the direction of the wind and whether the wind or slope vector is longest. Figure IV-8 presents sample vectors for a range of conditions. If the wind is blowing directly downslope or within ± 30° of directly downslope, the effects of wind and slope will be in direct opposition. Estimate fire spread in the direction of the strongest influence (largest spread distance vector) for a distance equal to the difference of the two. For example, if the wind is blowing directly downhill with a predicted spread distance of 15 chains and the slope vector is 5 chains (slope vector is always upslope), the resultant vector will be downhill a distance of 10 chains.

Backing Fire

The previously described methods have been designed for application to the head of the fire. If a prediction of spread and intensity is needed for a backing fire, that is a section of the fireline that is backing into the wind, or downslope, or both, use zero windspeed and zero slope as input values. This should also be considered as the minimum or limiting condition for spread rate when combining vectors.

Limitations

The process just explained will overpredict spread distance if both the wind and slope are low. But for most conditions, the results give good approximations and they are simple enough to apply without the aid of a computer.

Plot New Fire Position

Indicate the spread distance from each projection point with a vector. Use the maximum spread distance vectors as anchor points and sketch the probable location of the fireline. Between vectors, use the general elliptical shape of fire as a guide for segments of the fire. Take into account topography, such as ridges and gullys where fire may be slowed or accelerated by wet or more concentrated fuels. An example is shown in figure IV-9. The line connecting the spread vectors represents the probable growth of the fire during the projection time.

For extended periods the process can be repeated for sequential time periods, using the calculated line for the base of the next projection as shown in figure IV-10. For each new time period set up new projection points along the new fireline on a new overlay and recalculate using a new data sheet.

Interpretation of Spread and Intensity

When the wind is crossing upslope, the resultant spread vector is longer than the individual wind or slope vectors. Therefore, the combined rate of spread and fireline intensity will be greater than the value calculated for either wind or slope alone. In some cases you may wish to know the increased values to help interpret fire intensity. The combined rate of spread is directly proportional to the length of the resultant vector and can be determined by finding the ratio of its length to either the wind or slope vector. Rather than measure and calculate this value, it is easier and quicker to estimate the relative lengths of the resultant spread vector to either the wind or slope vector and then increase the spread rate by that proportion. For example, if the resultant spread vector is half again as long as the wind vector and the rate of spread in the wind column was 10 ch/h, then the combined resultant rate of spread would be about 15 ch/h.

The heat per unit area is not affected by wind or slope so the calculated value is correct for the resultant vector. The fireline intensity is not linearly related, but can be calculated by the formula in the appendix or you can determine it on the fire characteristics chart along with flame length. To do this, use figure IV-1, 2, or 3 and plot the increased rate of spread just estimated for the resultant versus the calculated heat per unit area. The resulting point on the chart indicates the expected fireline intensity and flame length. Interpret fire behavior and resistance to control for this section of the fire by the location of this point. On the same fire characteristics chart plot the behavior of the fire determined at the other projection points.

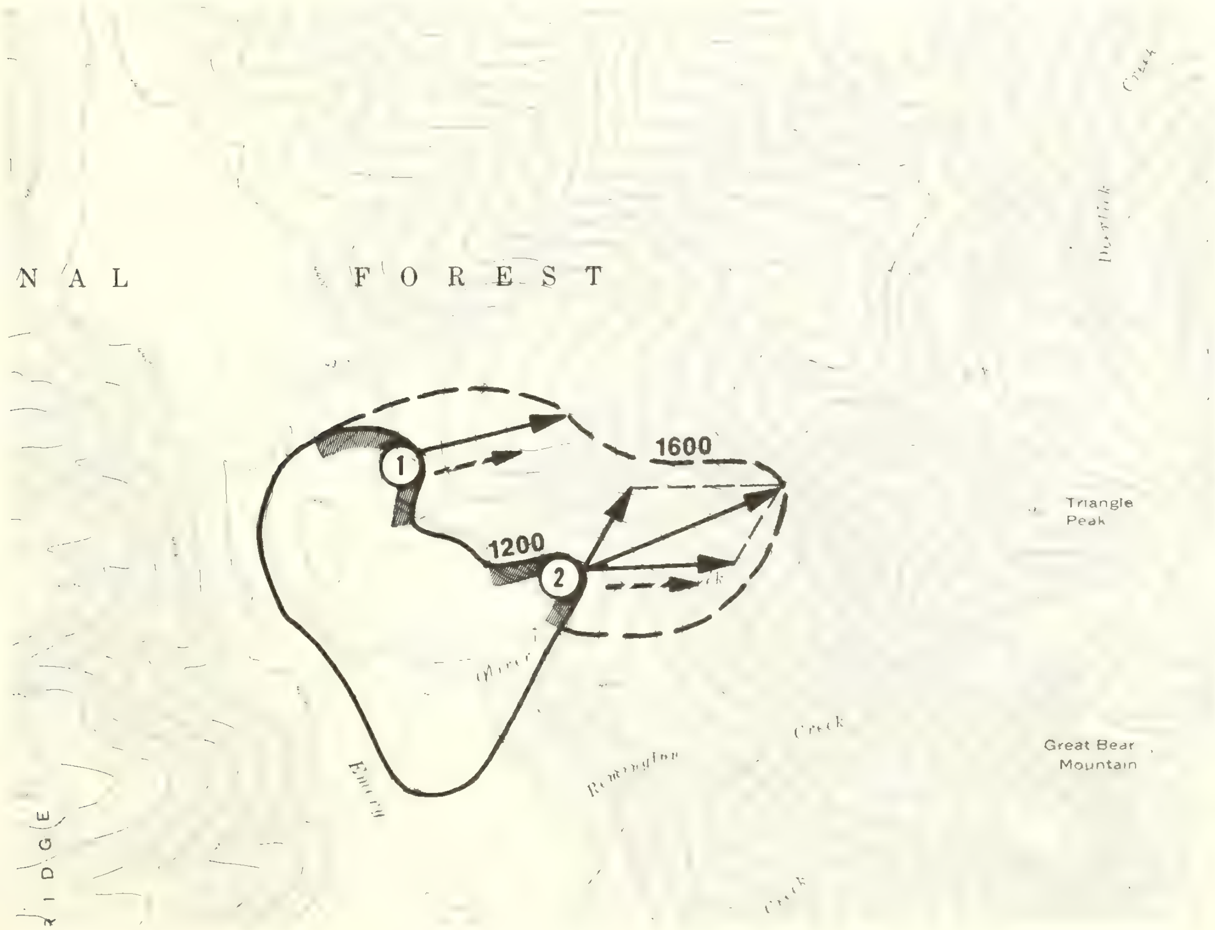


Figure IV-9.—Projected fireline.

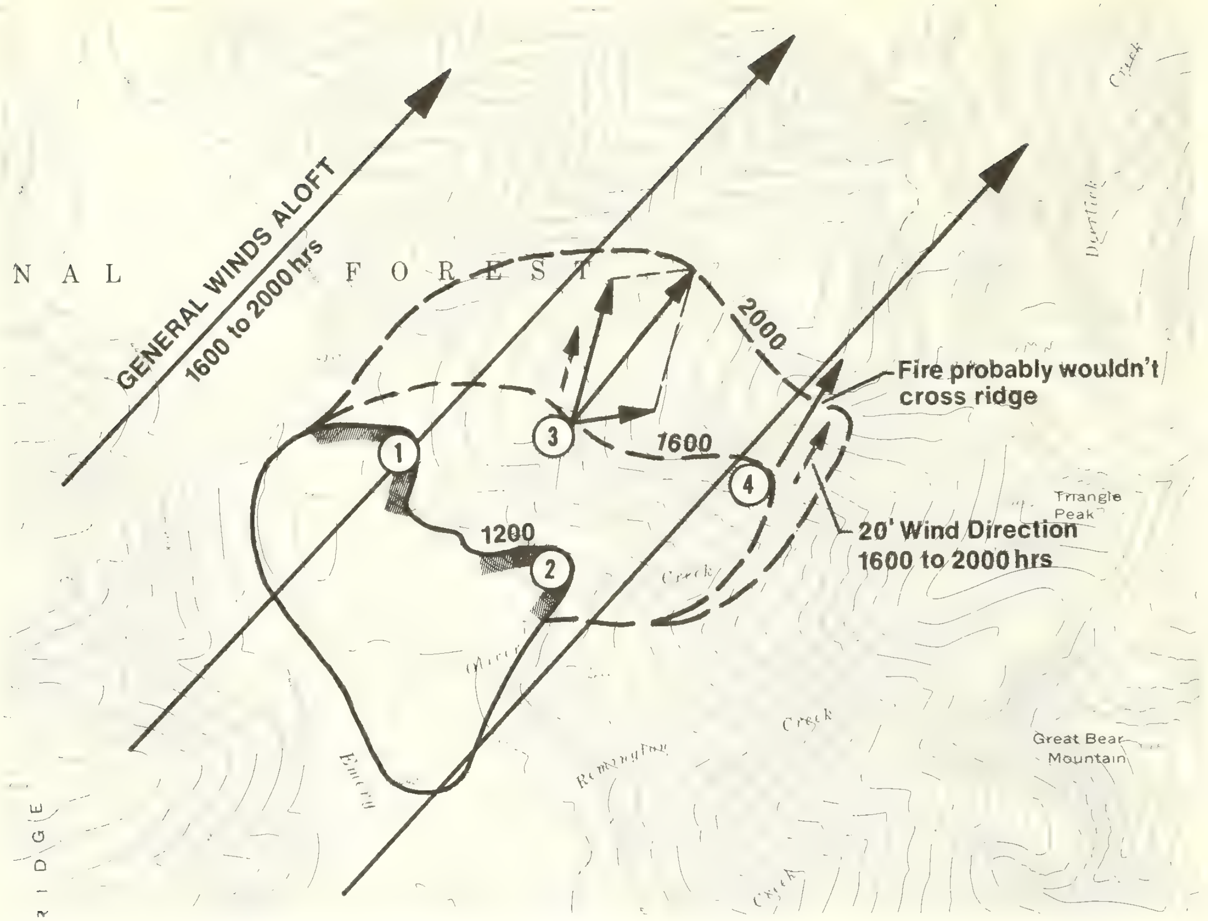


Figure IV-10.—Projected fire spread over sequential time periods.

Interpretation of severe fire and the potential for spotting that may be indicated by the location of the points are presented in the next section.

If the wind is blowing cross-slope in a downhill direction, the effects of wind and slope on fire spread will be counteracting each other rather than reinforcing. The resulting spread distance will be less than if the wind were the same speed on a flat slope. Since the spread distance is less, the actual rate of spread, fireline intensity, and flame length must also be less than the values calculated to indicate the influence of wind and slope separately. If you need these reduced values for interpreting fire behavior, they can be determined as described above.

Transmittal of Information

Use the information on your worksheet, the map projections, and the fire characteristics chart to prepare a fire behavior forecast for briefing the fire overhead team. Do not give raw numbers to the fire overhead team without interpretation unless requested to do so. The entire process of information transfer for an actual fire is illustrated in appendix G.

EXAMPLES

These methods are illustrated in the following examples:

Big Foot Ranch Fire Exercise

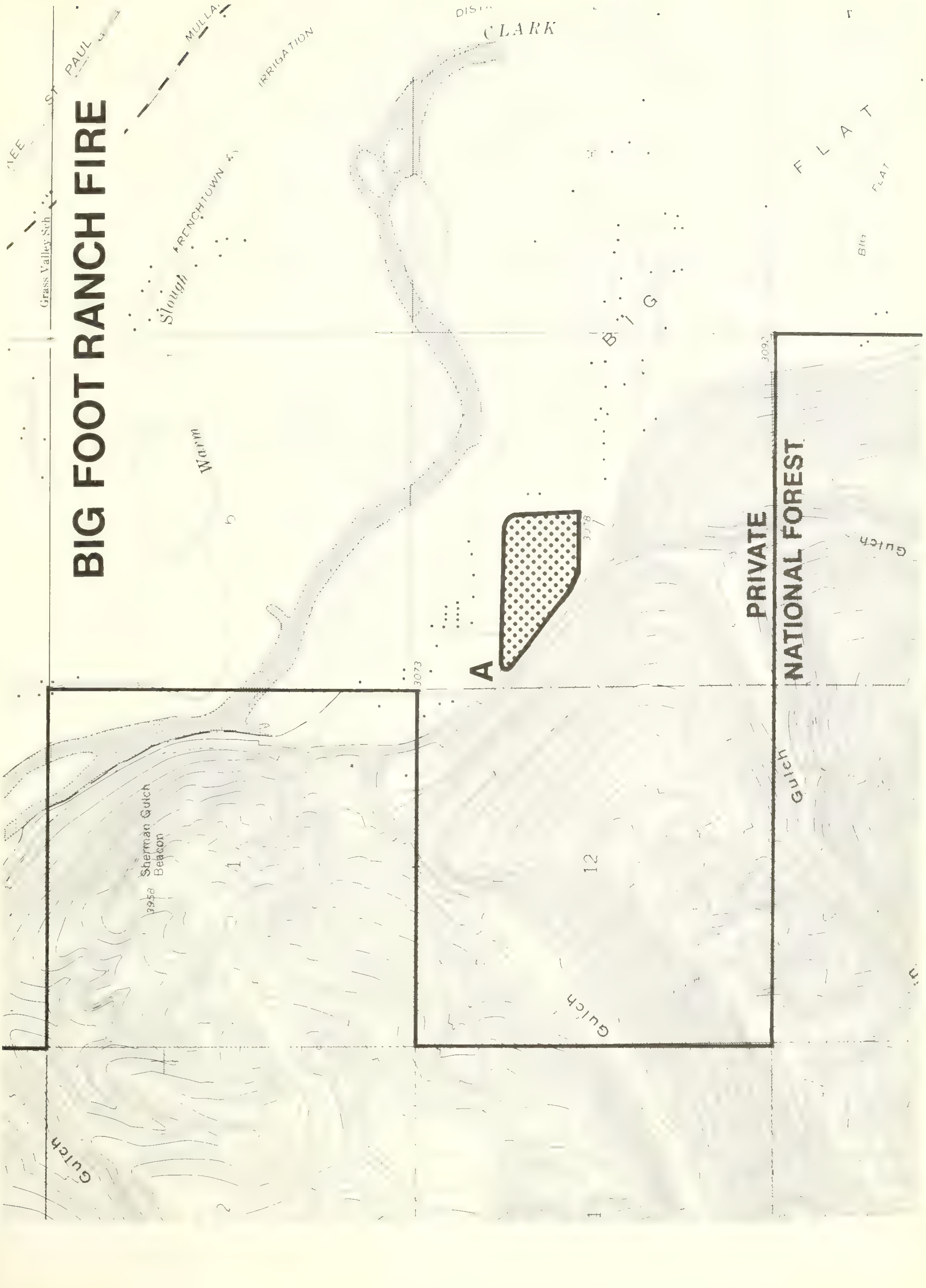
(hypothetical fire to illustrate vectoring)

Problem: The Big Foot Ranch has called to let you know they will be burning stubble on their land. You are concerned about the possibility of the fire escaping at point A on the map, because firelines are weak. The burn is to begin at 1300 on March 15.

The general forecast for the day is for a high temperature of 75° F and relative humidity of 38 percent. General winds are east at 15 mi/h. The slope above the burn area is best described as fuel model 6.

1. If a slopover occurs at 1400 hours, show the approximate perimeter of the fire by 1700.
2. Your supervisor wants to know if the fire would reach public land in the first 3 hours.
3. Could firefighters with hand tools control this fire?

Answers:
1. See map.
2. No.
3. The resultant spread vector is 1.6 times as long as the wind vector indicating that the rate of spread is 16 chains per hour. Plotting the resultant rate of spread versus the heat per unit area on a fire characteristics chart indicates the flame length will be at least 4 ft and probably more, making this a difficult fire to control with hand tools until it reaches a natural barrier such as the ridgetop.


BIG FOOT RANCH FIRE
PRIVATE
NATIONAL FOREST
A
Sherman Gulch
Beacon
3958
3073
12
Gulch
Gulch
Gulch
Warm
Slough
FRENCHTOWN
IRRIGATION
CLARK
B I G
F L A T
Grass Valley Sch
PAUL

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	A			
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	75			
d. Relative humidity, %	38			
e. Reference fuel moisture, % (from table A)	5			
f. Month	3			
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	1400			
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	E			
k. Slope	44			
l. Fuel moisture correction, % (from table B, C, or D)	2			
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	7			
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of ____

NAME OF FIRE Big Foot Ranch FIRE BEHAVIOR OFFICER Flaming Aero

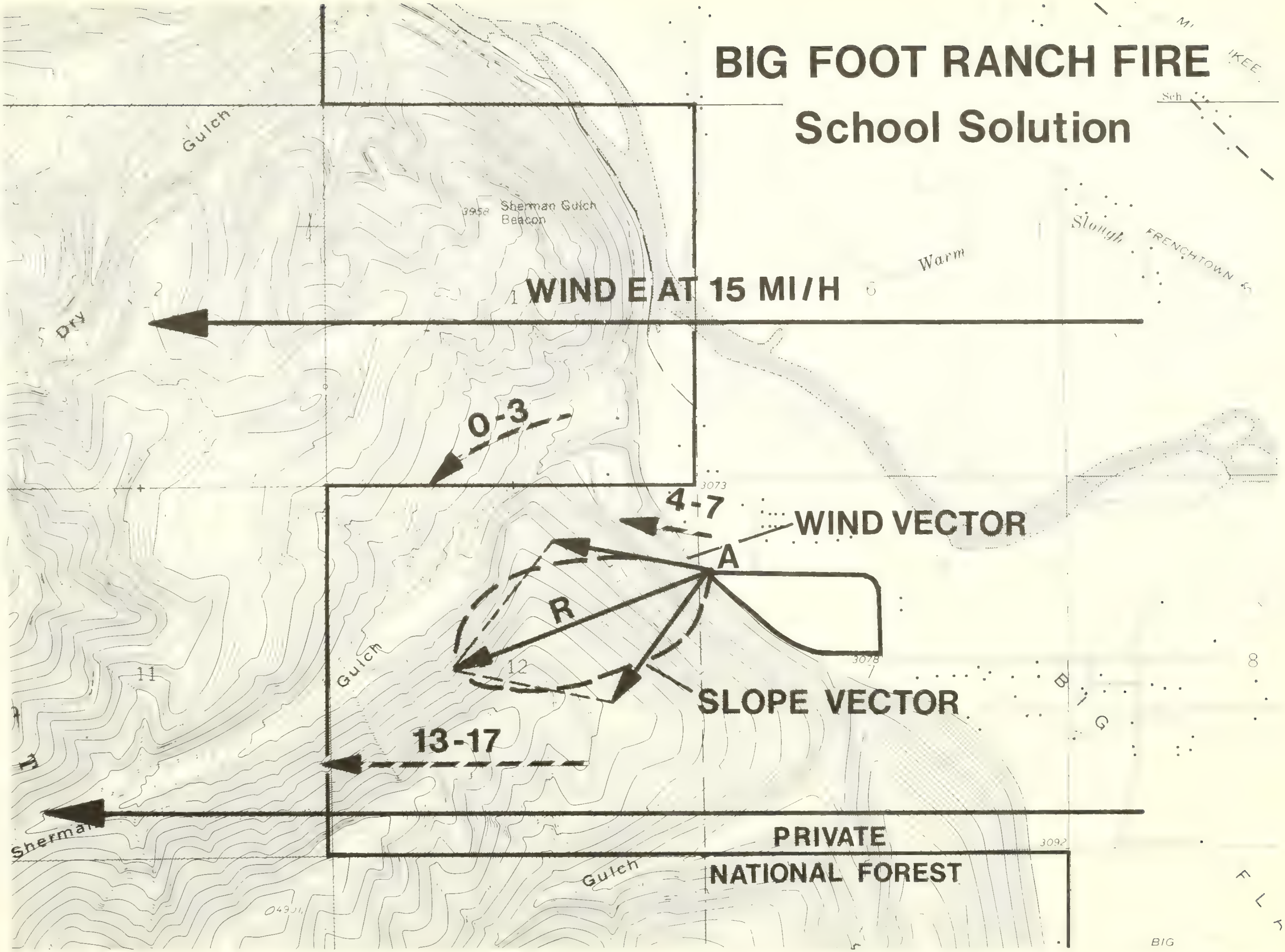
DATE 3-15 TIME 1400

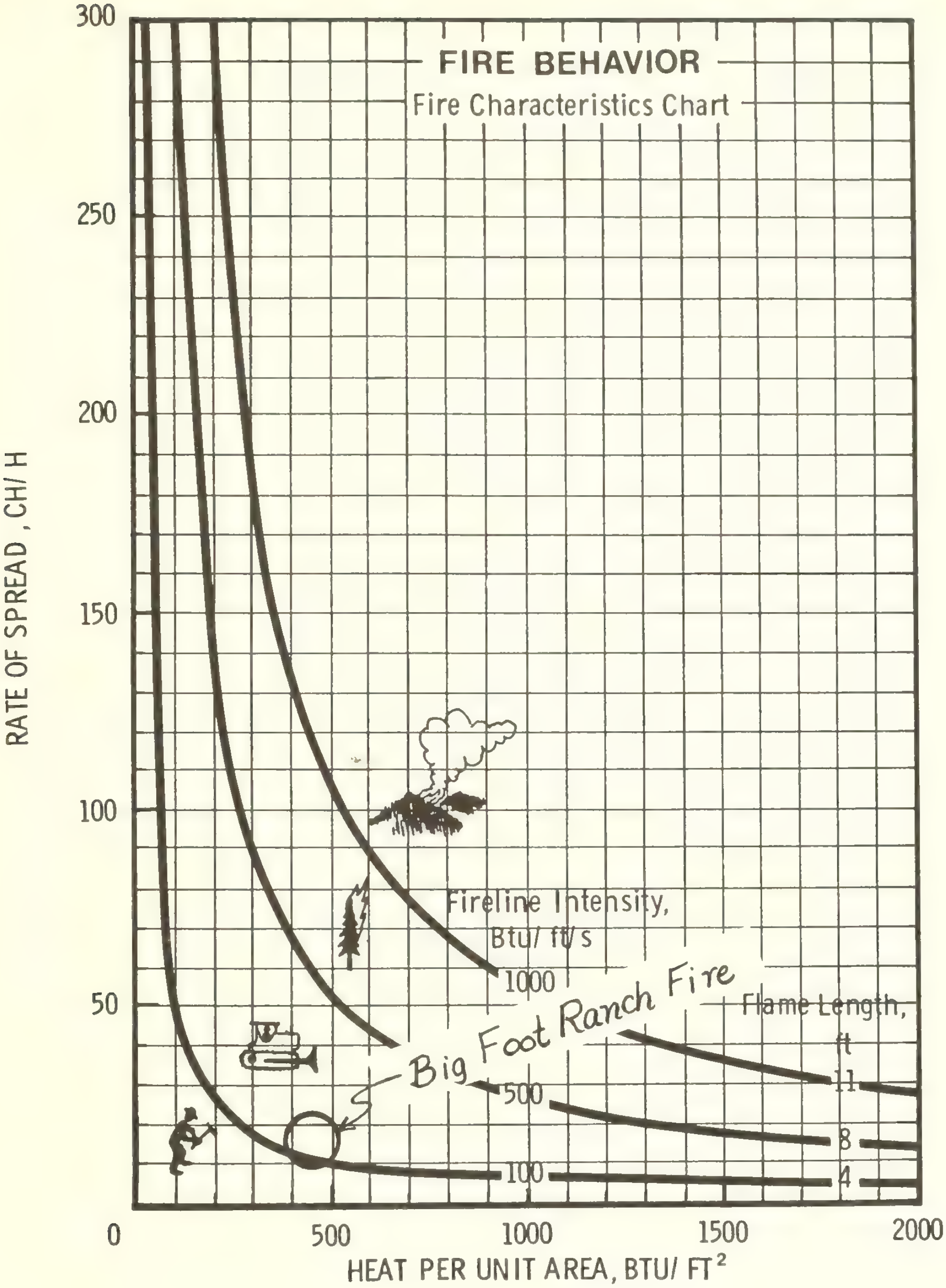
PROJ. PERIOD DATE 3-15 PROJ. TIME FROM 1400 to 1700

INPUT DATA							TI-59 Reg. No.
1	Projection point		A				
2	Fuel model proportion, %		100				
3	Fuel model		6				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0				60
5	Dry bulb temperature, °F	DB	75				61
6	Relative humidity, %	RH	38				62
7	1 H TL FM, %	1H	7				28
8	10 H TL FM, %	10H	9				63
9	100 H TL FM, %	100H	11				30
10	Live fuel moisture, %	LIVE	-				33
11	20-foot windspeed, mi/h		(4-7)	( )	( )	( )	
12	Wind adjustment factor	exposed	(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	2	0			79
14	Maximum slope, %	PCT S	0	44			80
15	Projection time, h	PT	3				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	10	11			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	449	449			90
21	Fireline intensity, Btu/ft/s	[B]	INT	85	87			53
22	Flame length, ft	[R/S]	FL	3	4			54
23	Spread distance, ch	[C]	SD	31	32			42
24	Map distance, in	[R/S]	MD	1.0	1.0			43
25	Perimeter, ch	[D]	PER	-	-			40
26	Area, acres	[R/S]	AREA	-	-			89
27	Ignition component, %	[E]	IC	-	-			44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	-	-			52

BIG FOOT RANCH FIRE
School Solution





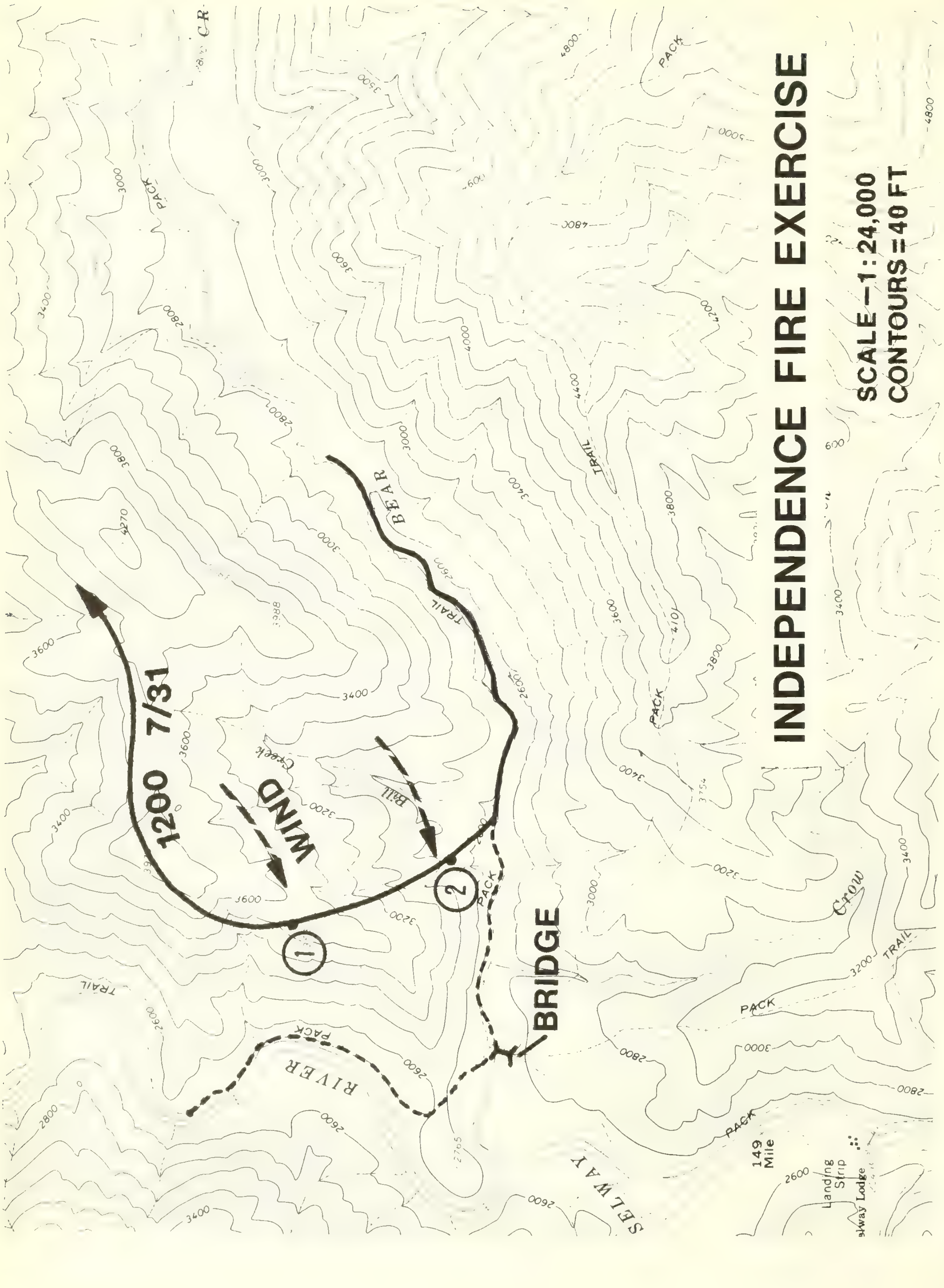
Independence Wilderness Fire Exercise[4]

The Independence Fire started on July 3, 1979, and was detected on the 4th, hence the name "Independence." The fire occurred on the Moose Creek Ranger District, Nezperce National Forest. The Moose Creek District is entirely within the Selway-Bitterroot Wilderness and under a natural fire program. This fire was allowed to burn freely and was monitored closely throughout the 1979 season.

Ignition occurred on a south slope 6 miles up Bear Creek and the fire burned westward into the wind toward the Selway River for 3 to 4 weeks. North and east spread was arrested because of high dead fuel and live fuel moistures. Spread to the south was inhibited by Bear Creek. Timber on the south and west slopes is scattered ponderosa pine. During this 3- to 4-week period, spread and intensity were low, i.e., 1 ch/h and approximately 25 to 50 Btu/ft/s. Some torching of trees resulted, but most spread was confined to the ground.

The past 3 to 4 weeks indicated consistent up-canyon daytime winds, followed by an inversion each night. The fire was very "predictable." At the mouth of Bear Creek, the light up-canyon winds circulated so that they were coming from the east over this section of the fire (see map).

[4]Fire management in the Selway-Bitterroot Wilderness, Nezperce National Forest: a report of the 1979 fire season and Independence Fire, by Larry D. Keown, USDA For. Serv., Northern Region, May 1980.


INDEPENDENCE FIRE EXERCISE
SCALE —1:24,000
CONTOURS = 40 FT
1200 7/31
WIND
BRIDGE
BEAR
TRAIL
Bill Creek
PACK
RIVER
SELWAY
Crow
149 Mile
Landing Strip
1
2

Situation:

As the fire approaches the mouth of Bear Creek, concern grows over the safety of two items: the bridge at the mouth of Bear Creek, and private property about 1 mile up the Selway. As district Fire Management Officer (FMO), you have called up a small crew to burn out around the bridge and along the Selway River Trail (marked by ---- on the attached map). Your strategy is to begin the burnout operation when winds become calm (about 1800). Information you have collected is as follows:

Date – July 31, 1979, 1200 hours
Perimeter – see map
Projection points – on map (1 and 2)
Shading – 20–30% canopy
Fuels – Model 9
Fuel moisture – 1-hour – use charts
10-hour – 6% (at nearest NFDRS station)
100-hour – 7%
Live – 100%
Weather – see spot forecast (note: use the local wind direction shown on the map)

FIRE WEATHER SPECIAL FORECAST REQUEST

(See reverse for instructions)

I. REQUESTING AGENCY WILL FURNISH:

1. NAME OF FIRE OR OTHER PROJECT	2. CONTROL AGENCY	3. REQUEST MADE TIME†	DATE
INDEPENDENCE		0800	7/31

4. LOCATION (By ¼ Sec · Sec · Twp · Range)	5. DRAINAGE NAME	6. EXPOSURE (NE, E, SE, etc.)
	SELWAY RIVER	WEST

7. SIZE OF PROJECT (Acres)*	8. ELEVATION* TOP	BOTTOM	9. FUEL TYPE	10. PROJECT ON:
2400	6500	2500	PP. DF	X GROUND CROWNING

11. WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS *(See example on reverse)*

PLACE	ELEVATION	OB TIME†	WIND DIR.-VEL. 20 FT.	WIND DIR.-VEL. EYE LEVEL	TEMP. DRY	TEMP. WET	‡(Leave blank) RH	‡(Leave blank) DP	REMARKS (Indicate rain, thunderstorms, etc. Also wind condition and 10ths of cloud cover)
FIRE	2700	7/30 1400		W 0-2	87	61			CLEAR
"	2800	7/30 1700		SW 5-7	86	58			"
"	2750	7/31 0745		SW 1-2	53	48			"

12. SEND FORECAST TO:	PLACE	VIA	ATTN: (Name, if applicable)

II. FIRE WEATHER FORECASTER WILL FURNISH:

13. FORECAST AND OUTLOOK (SPECIFY WIND 20 FOOT OR EYE LEVEL) TIME† AND DATE:

0830 TODAY

FAIR; LAL = 1; CHANCE OF RAIN = 0%; HI TEMP = 90° BOTTOM, 80° TOP; RH = 18% BOTTOM, 12% TOP; WINDS LIGHT, UPCANYON 4-8; GENERAL WINDS W 10-15

NAME OF FIRE WEATHER FORECASTER	FIRE WEATHER OFFICE
LIGHTNING ROD GOENS	MISSOULA

III. REQUESTING AGENCY WILL COMPLETE UPON RECEIPT OF FORECAST

IV. FORECAST RECEIVED:	TIME†	DATE	NAME

Explanation of Symbols:
- † Use 24-hour clock to indicate time. Example: 10:15 p.m. = 2215; 10:15 a.m. = 1015.
- * For concentrations (as groups of lightning fires) specify "Concentration"; then give number of fires and size of largest. If concentrations are in more than one drainage, request special forecast for each drainage.
- ‡ No entry necessary. To be computed by the Fire Weather Forecaster.

a.	Projection point	1	2		Burnout
b.	Day or night (D/N)	D/N	D/N	D/N	D/N
	DAY TIME CALCULATIONS				
c.	Dry bulb temperature, °F	85	85		80
d.	Relative humidity, %	16	16		20
e.	Reference fuel moisture, % (from table A)	2	2		3
f.	Month	7	7		7
g.	Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h.	Time	1400	1400		1800
i.	Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j.	Aspect	W	S		S
k.	Slope	+30	+30		+30
l.	Fuel moisture correction, % (from table B, C, or D)	1	1		3
m.	Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	3	3		6
	NIGHT TIME CALCULATIONS				
n.	Dry bulb temperature, °F				
o.	Relative humidity, %				
p.	Reference fuel moisture, % (from table E)				
	Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q.	Aspect of projection point				
r.	Aspect of site location				
s.	Time				
t.	Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u.	Correction for projection point location (from table F)				
v.	Correction for site location (L) (from table F)				
w.	Fuel moisture correction, % (line u - line v)				
x.	Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

Problem:

1. What will be the probable perimeter at 1800 hours?
2. If the burnout begins after winds subside (1800), would the fire's uphill spread result in intensities great enough to cause torching, crowning, or spotting?

Discussion:

At projection point 1, the fire will be backing down a steep (57 percent) slope. The uphill slope effect is stronger than the downhill wind effect as shown by the spread distances in columns 1 and 2 of worksheet 1. The instructions say, however, that the fire should always be considered to have the capability of spreading at a rate computed with zero wind and zero slope. This calculation was made in column 3 of sheet 1. The spread distance scaled to the map is only 0.2 inches. A vector of this length is plotted. In this situation, however, rolling debris, particularly pine cones, can carry fire down the slope where new fires can be started, which will run back up the slope.

At projection point 2, the wind is blowing cross-slope along the south-facing slope. The projection point was selected about midslope. Discounting the small gully just ahead of the fire, the average slope in this area is about 40 percent. The resultant vector extends beyond a ridge where the fire would have to back down a northwest slope. Its spread would be slowed and so the projected fireline was not extended to the end of the vector. On the south slope, however, the fire would probably spread the length of the resultant vector.

The burnout operation can probably be conducted without problems due to torching, crowning, or spotting. To aid interpretation, all three points are plotted on a fire characteristics chart with log scales, which clearly differentiates these low-intensity fires.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 3

NAME OF FIRE Independence FIRE BEHAVIOR OFFICER FMO

DATE 7/31/79 TIME 1200

PROJ. PERIOD DATE 7/31/79 PROJ. TIME FROM 1200 to 1800

INPUT DATA

								TI-59 Reg. No.
1	Projection point			1	1	1		
2	Fuel model proportion, %			100				
3	Fuel model			9				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	1				60
5	Dry bulb temperature, °F		DB	85				61
6	Relative humidity, %		RH	16				62
7	1 H TL FM, %		1H	3				28
8	10 H TL FM, %		10H	6				63
9	100 H TL FM, %		100H	7				30
10	Live fuel moisture, %		LIVE	100				33
11	20-foot windspeed, mi/h			(4-8)	( )	( )	( )	
12	Wind adjustment factor			(.3)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	2	0	0		79
14	Maximum slope, %		PCT S	0	57	0		80
15	Projection time, h		PT	6				81
16	Map scale, in/mi		MS	2.64				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	3	7	1		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	448	448	448		90
21	Fireline intensity, Btu/ft/s	[B]	INT	27	58	9		53
22	Flame length, ft	[R/S]	FL	2	3	1		54
23	Spread distance, ch	[C]	SD	20	42	6.8		42
24	Map distance, in	[R/S]	MD	0.7	1.4	0.2		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

NAME OF FIRE Independence FIRE BEHAVIOR OFFICER FMO

DATE 7/31/79 TIME 1200

PROJ. PERIOD DATE 7/31/79 PROJ. TIME FROM 1200 to 1800

INPUT DATA

							TI-59 Reg. No.
1	Projection point		2	2			
2	Fuel model proportion, %		100				
3	Fuel model		9				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	1				60
5	Dry bulb temperature, °F	DB	85				61
6	Relative humidity, %	RH	16				62
7	1 H TL FM, %	1H	3				28
8	10 H TL FM, %	10H	6				63
9	100 H TL FM, %	100H	7				30
10	Live fuel moisture, %	LIVE	100				33
11	20-foot windspeed, mi/h		(4-8)	( )	( )	( )	
12	Wind adjustment factor		(.3)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	2	0			79
14	Maximum slope, %	PCT S	0	40			80
15	Projection time, h	PT	6				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	3	4			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1446	1446			90
21	Fireline intensity, Btu/ft/s	[B]	INT	89	95			53
22	Flame length, ft	[R/S]	FL	4	4			54
23	Spread distance, ch	[C]	SD	20	21			42
24	Map distance, in	[R/S]	MD	.7	.7			43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 3

NAME OF FIRE Independence FIRE BEHAVIOR OFFICER FMO

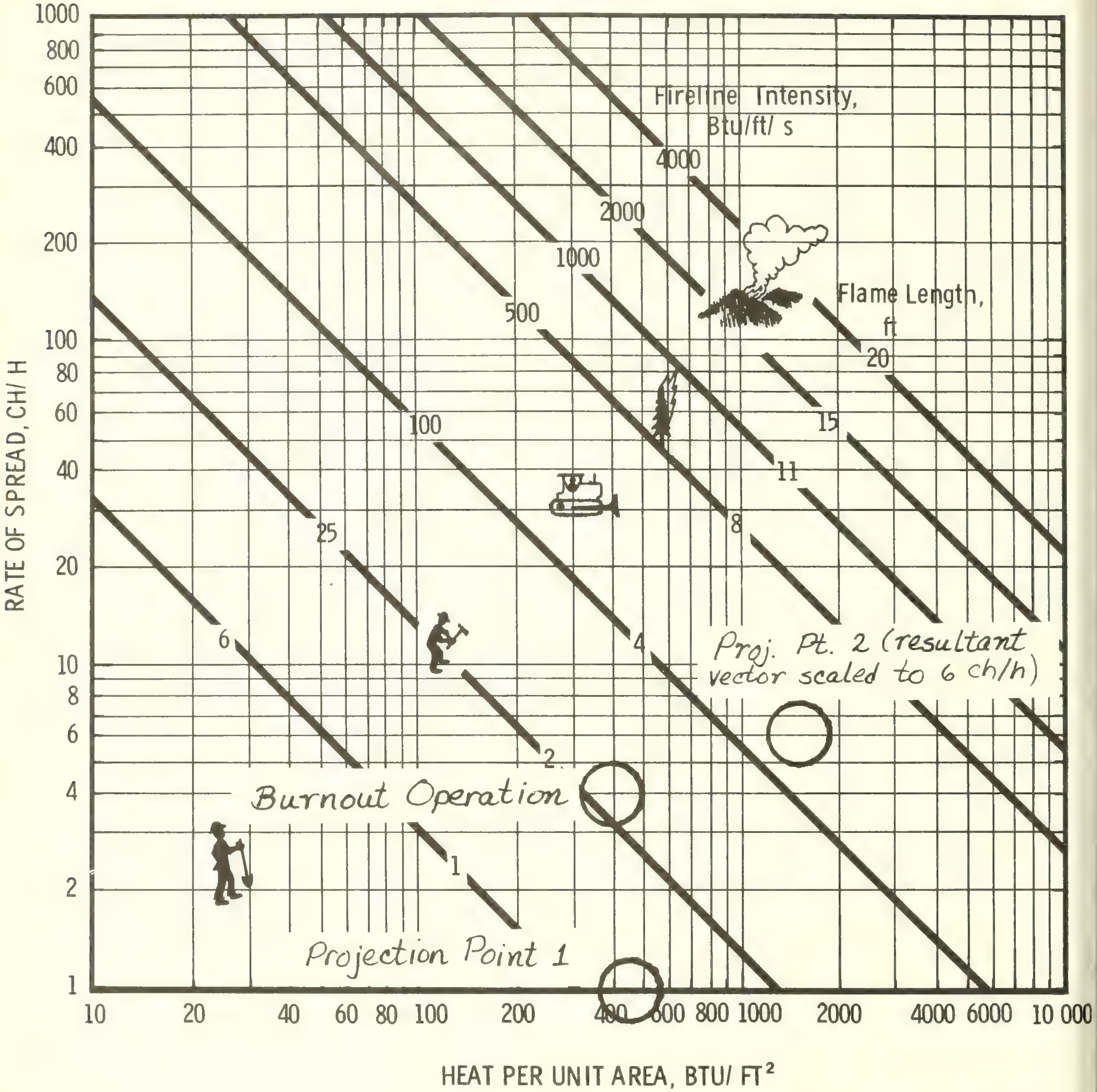
DATE 7-31 TIME 1200

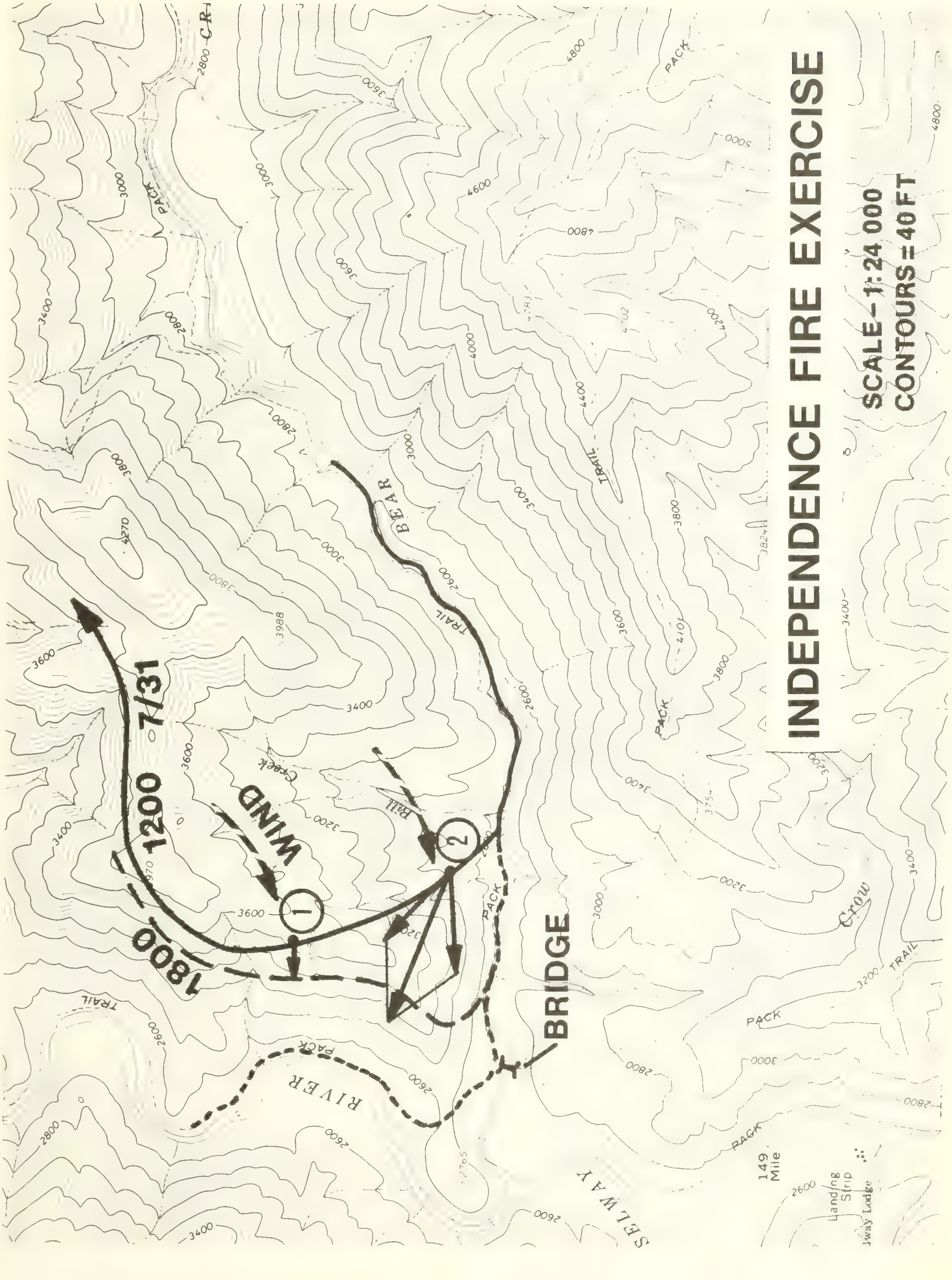
PROJ. PERIOD DATE 7-31 PROJ. TIME FROM 1800 to 1900

	INPUT DATA								TI-59 Reg. No.
1	Projection point				Burnout				
2	Fuel model proportion, %				100				
3	Fuel model				9				
4	Shade value	(0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	1				60
5	Dry bulb temperature, °F			DB	80				61
6	Relative humidity, %			RH	20				62
7	1 H TL FM, %			1H	6				28
8	10 H TL FM, %			10H	6				63
9	100 H TL FM, %			100H	7				30
10	Live fuel moisture, %			LIVE	100				33
11	20-foot windspeed, mi/h				(0)	( )	( )	( )	
12	Wind adjustment factor				(–)	( )	( )	( )	
13	Midflame windspeed, mi/h			M WS	0				79
14	Maximum slope, %			PCT S	50				80
15	Projection time, h			PT	1				81
16	Map scale, in/mi			MS	2.64				82
17	Map conversion factor, in/ch								
18	Effective windspeed, mi/h								
	OUTPUT DATA								
19	Rate of spread, ch/h		[A]	ROS	4				88
20	Heat per unit area, Btu/ft^2		[R/S]	H/A	370				90
21	Fireline intensity, Btu/ft/s		[B]	INT	28				53
22	Flame length, ft		[R/S]	FL	2				54
23	Spread distance, ch		[C]	SD	4.2				42
24	Map distance, in		[R/S]	MD	0.1				43
25	Perimeter, ch		[D]	PER					40
26	Area, acres		[R/S]	AREA					89
27	Ignition component, %		[E]	IC	21				44
28	Reaction intensity, Btu/ft^2/min		[R/S]	IR					52

FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)




INDEPENDENCE FIRE EXERCISE
SCALE—1:24 000
CONTOURS=40 FT
WIND
1200 7/31
1800
BRIDGE
BEAR
TRAIL
PACK
RIVER
SELWAY
Crow
Bill
Creek
149 Mile
Landing Strip
Selway Lodge

Paul Bunyan Fire – Huron National Forest of Michigan
(hypothetical fire to illustrate fire growth by successive periods through different fuels)

Situation:

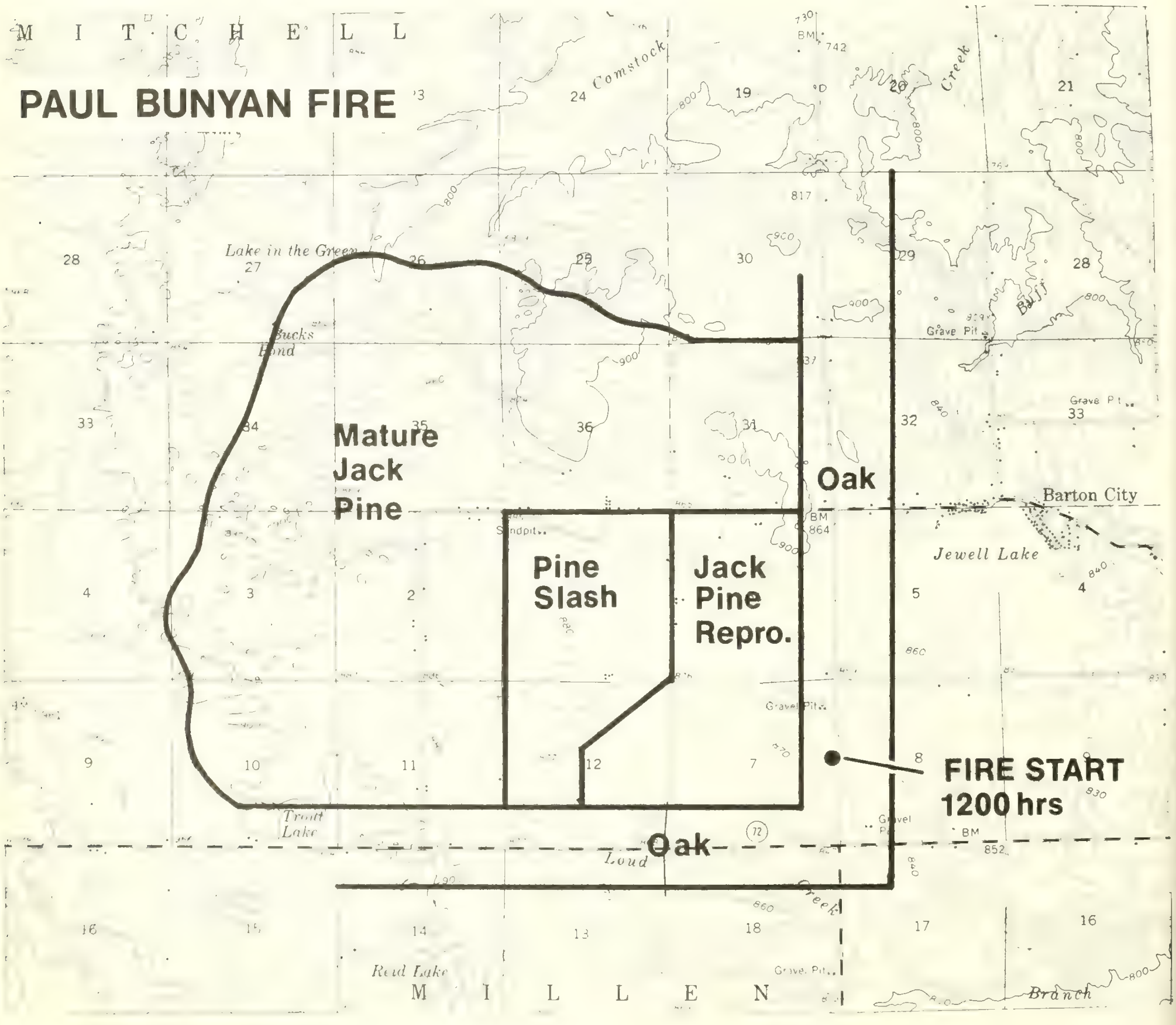
After a long, exceptionally dry summer, a fire is found to have started alongside a road in oak litter. The hardwood trees have lost most of their leaves. Beyond the oak stand lies jack pine reproduction 3 ft high interspersed with grass and weeds. The jack pine reproduction covers about 70 percent of the area. The grass and weeds are entering dormancy. The area also includes sparse stands of mature jack pine, with some logging slash from spring cutting (see fuel map). Jack pine is a shade-intolerant species, with needles 3/4 to 1-1/2 inches long. The slash is red and at about 25 tons per acre. The mature jack pine is in a closed stand, with compact needles forming the litter.

It is 1200 on October 27, temperature = 72° F, relative humidity = 33-45 percent, and there is 10 percent cloud cover. The wind is from the east at 18 to 22 miles per hour. After 1 hour it switches to the southeast and decreases to 15 to 20 miles per hour.

Show the probable fire location after 1, 2, and 3 hours. Plot fire behavior predictions on a fire characteristics chart.

Questions:

1. Does the fire burn into the slash by the end of 3 hours?
2. What is the probability of spot fire ignition in the slash?
3. What conclusions can you draw concerning fire suppression:
   a. in the oak?
   b. in the jack pine reproduction?
   c. in the pine slash?
   d. in the mature jack pine stand?
4. When the winds stop and the fire is contained, mopup must begin. What soils characteristic in some parts of the Lake States makes mopup particularly difficult?



a. Projection point	1	2	3	4
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	72			
d. Relative humidity, %	45			
e. Reference fuel moisture, % (from table A)	7			
f. Month	Oct			
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	1200	1300	1330	1400
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	—			—
k. Slope	0			—
l. Fuel moisture correction, % (from table B, C, or D)	1			4
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	8	8	8	11
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists <u>and</u> a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 3

NAME OF FIRE Paul Bunyan FIRE BEHAVIOR OFFICER School Solution

DATE ______ TIME ______

PROJ. PERIOD DATE 10/27/79 PROJ. TIME FROM 1200 to 1300

INPUT DATA			First hour				TI-59 Reg. No.
1	Projection point		1				
2	Fuel model proportion, %		100				
3	Fuel model		9				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0				60
5	Dry bulb temperature, °F	DB	72				61
6	Relative humidity, %	RH	45				62
7	1 H TL FM, %	1H	8				28
8	10 H TL FM, %	10H					63
9	100 H TL FM, %	100H					30
10	Live fuel moisture, %	LIVE	—				33
11	20-foot windspeed, mi/h		(18-22)	( )	( )	( )	
12	Wind adjustment factor		(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	8				79
14	Maximum slope, %	PCT S	0				80
15	Projection time, h	PT	1				81
16	Map scale, in/mi	MS	1				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	16				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	343				90
21	Fireline intensity, Btu/ft/s	[B]	INT	102				53
22	Flame length, ft	[R/S]	FL	4				54
23	Spread distance, ch	[C]	SD	16.1				42
24	Map distance, in	[R/S]	MD	0.2				43
25	Perimeter, ch	[D]	PER	44				40
26	Area, acres	[R/S]	AREA	11				89
27	Ignition component, %	[E]	IC	29				44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	2221				52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 3

NAME OF FIRE Paul Bunyan FIRE BEHAVIOR OFFICER School Solution

DATE ______ TIME ______

PROJ. PERIOD DATE 10/27/79 PROJ. TIME FROM 1300 to 1500

INPUT DATA

Next 2 hours

								TI-59 Reg. No.
1	Projection point			2	2	2		
2	Fuel model proportion, %			30	70	30/70		
3	Fuel model			2	6	2&6		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0				60
5	Dry bulb temperature, °F		DB	72				61
6	Relative humidity, %		RH	45				62
7	1 H TL FM, %		1H	8				28
8	10 H TL FM, %		10H					63
9	100 H TL FM, %		100H					30
10	Live fuel moisture, %		LIVE	50	-			33
11	20-foot windspeed, mi/h			(15-20)	( )	( )	( )	
12	Wind adjustment factor			(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	7				79
14	Maximum slope, %		PCT S	0				80
15	Projection time, h		PT	2		2		81
16	Map scale, in/mi		MS	1				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	70	46	53		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	475	439			90
21	Fireline intensity, Btu/ft/s	[B]	INT	608	367			53
22	Flame length, ft	[R/S]	FL	9	7			54
23	Spread distance, ch	[C]	SD			106		42
24	Map distance, in	[R/S]	MD			1.4		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 3

NAME OF FIRE: Paul Bunyan   FIRE BEHAVIOR OFFICER: School Solution

DATE: ______   TIME: ______

PROJ. PERIOD DATE: 10/27/79   PROJ. TIME FROM ______ to ______

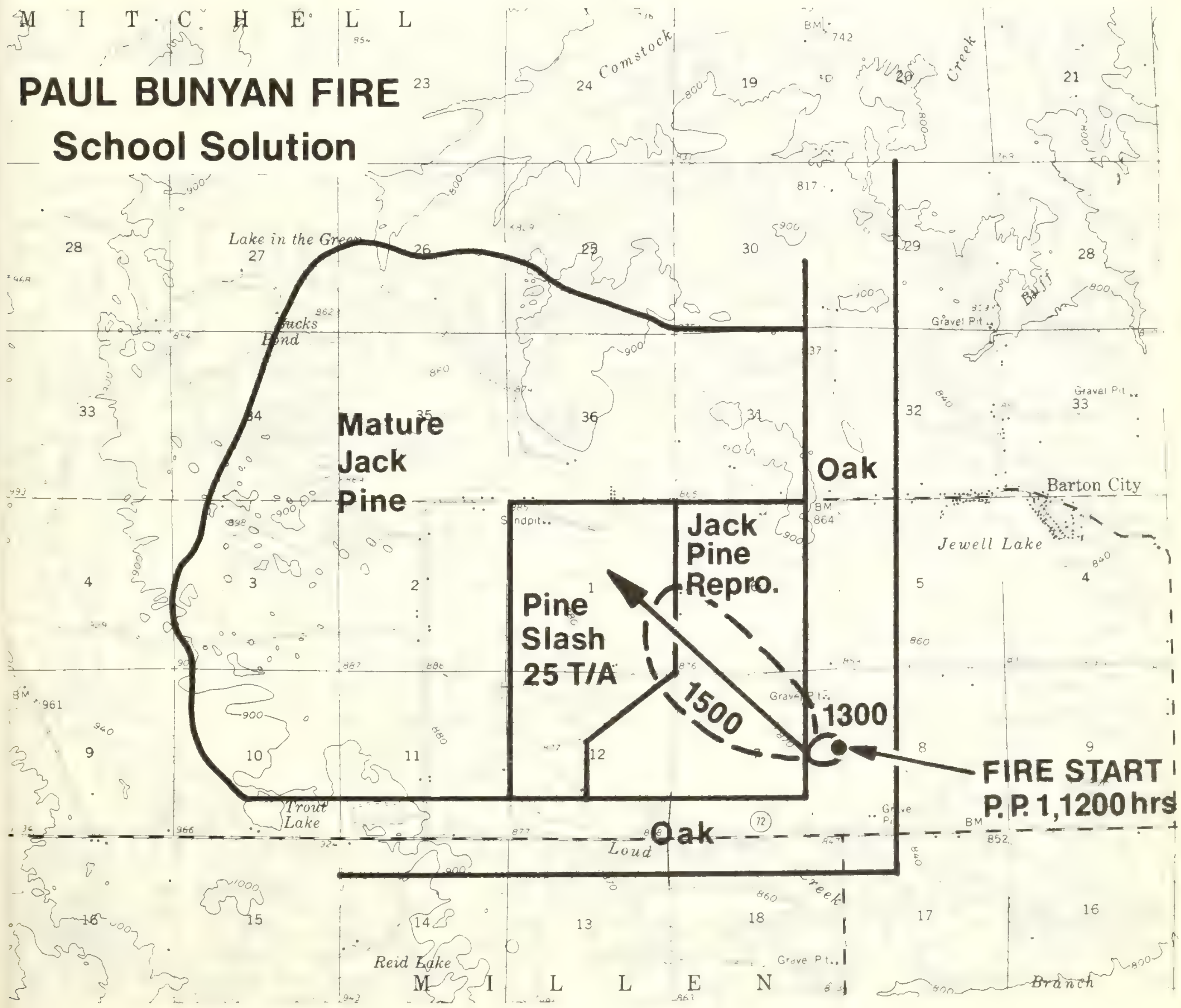
INPUT DATA

Check intensity in slash and burning conditions in mature jack pine.

								TI-59 Reg. No.
1	Projection point			3		4		
2	Fuel model proportion, %		slash	100		100	matur pine	
3	Fuel model			12		8		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0		2		60
5	Dry bulb temperature, °F		DB	72		72		61
6	Relative humidity, %		RH	45		45		62
7	1 H TL FM, %		1H	8		11		28
8	10 H TL FM, %		10H					63
9	100 H TL FM, %		100H					30
10	Live fuel moisture, %		LIVE	–		–		33
11	20-foot windspeed, mi/h			(15-22)	( )	(15-20)	( )	
12	Wind adjustment factor			(.4)	( )	(.2)	( )	
13	Midflame windspeed, mi/h		M WS	7		4		79
14	Maximum slope, %		PCT S	0		0		80
15	Projection time, h		PT	–		1		81
16	Map scale, in/mi		MS	–		–		82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							
	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	17		1		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	2112		162		90
21	Fireline intensity, Btu/ft/s	[B]	INT	654		3		53
22	Flame length, ft	[R/S]	FL	9		1		54
23	Spread distance, ch	[C]	SD			1.1		42
24	Map distance, in	[R/S]	MD			–		43
25	Perimeter, ch	[D]	PER			4		40
26	Area, acres	[R/S]	AREA			< 1/2		89
27	Ignition component, %	[E]	IC			9		44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR			–		52
	Ignition probability			40%		20%		

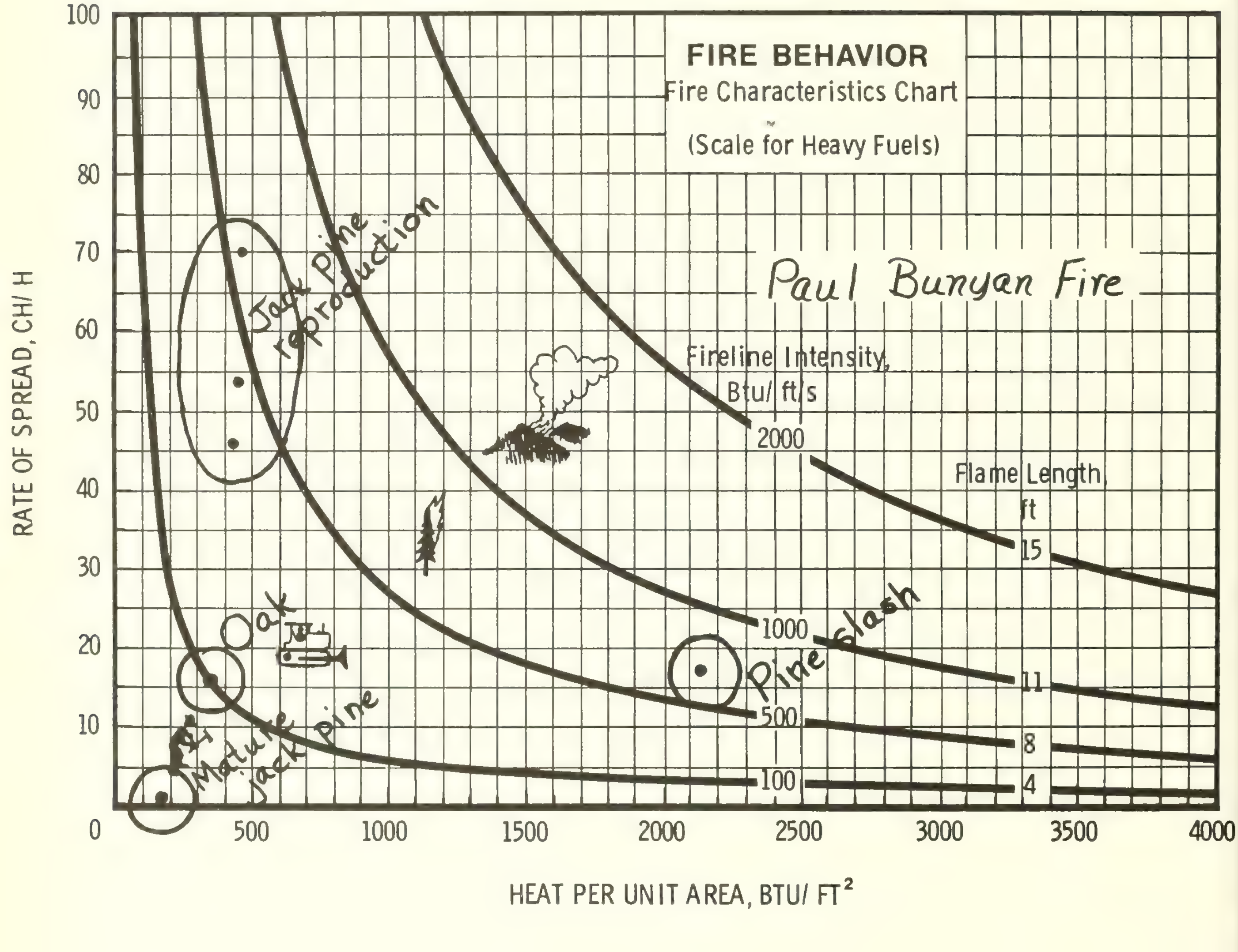
Paul Bunyan Fire – School Answers to Questions

1. Yes. The fire will reach the slash in about 2-1/2 hours.
2. Given: Dry bulb temperature = 72° F
   Cloud cover = 10%
   Fine fuel moisture = 8%
   Then: Fuel temperature = 92° F
   Ignition probability = 45%
3. Suppression interpretations:
   a. *In the oak*: Based on a fireline intensity of 102 Btu/ft/s, the fire is near the limit of direct attack with handtools. A hand line may not hold the fire. The road provides a firebreak on the east side of the fire. The fire will reach the jack pine reproduction in approximately 1 hour.
   b. *In the jack pine reproduction*: Since the area is best described by a mixture of two fuel models, the fire will exhibit a range of conditions as illustrated on the fire characteristics chart. The expected rate of spread is the weighted average of 53 ch/h. The fireline intensity will range between about 370 and 600 Btu/ft/s. Most of the area has a fireline intensity that indicates that equipment can be effective in controlling the fire, but that the fire may be potentially dangerous to personnel and equipment. The rest of the area will burn with an intensity that may present serious control problems. It will take about 1-1/2 more hours for the fire to burn through the reproduction and into the slash.
   c. *In the pine slash*: This fuel burns at a relatively low rate of spread but has a high heat per unit area. The fireline intensity indicates that spotting may occur and that control efforts at the fire head will probably be ineffective. According to the fuel model description, the fire will probably be sustained until a fuel break or change in fuels is encountered.
   d. *In the mature jack pine stand (PP #4)*: There is a chance that firebrands generated by the burning slash will reach the mature jack pine stand, but the probability of ignition within the stand is only 20 percent. Spot fires should be easily contained by persons using hand tools. In an hour, a spot fire would grow to an area of less than 0.5 acre, with a perimeter of 4 chains.



There is a better chance of the fire carrying into the stand from the slash. By this time, it will be later in the day and burning conditions will be poorer.

4. Peat is often found in this part of the country; fire continues to burn in the peat long after the surface fuels are consumed. The fire behavior models used in this manual were designed to describe the flaming edge of surface fires. They do not apply to the mopup problem.



Spotting and Crowning

INTRODUCTION

Table IV-1 indicates that when fireline intensity in surface fuels reaches 500 Btu/ft/s, severe fires can be expected. Flame lengths are about 8 ft, fire suppression techniques are becoming ineffective, and torching of tree crowns and spotting will begin. When fireline intensity reaches 1,000 Btu/ft/s, flame lengths could reach 11 ft and severe crown fire is very probable. If there is any chance of a fire reaching this stage, there is concern about whether the fire is going to spot beyond the firelines and whether it will crown and make a severe run. A large number of case studies have been written about severe fires and every region of the country has data on fuels, weather, and circumstances associated with severe fire. It is not the purpose of this manual to compile and condense these observations. Research in the United States, Canada and Australia is now concentrating on the study of severe fire so that predictive tools can be developed. This chapter covers a few techniques in spot fire distance, ignition of firebrands, and crowning that can be used in conjunction with the techniques developed for predicting surface fire behavior.

SPOTTING

A newcomer to an intense wildfire quickly learns the importance of spotting to the fire suppression team. A firebrand blown over established control lines can wipe out days of hard work by hundreds of firefighters.

The problem of spotting involves three factors:

1. The source of firebrands.
2. How far they travel.
3. The probability of ignition on landing.

The source of the firebrand can arise from several situations.

Short-range spotting.—Embers (often a shower of them) produced in the moving fire front are carried a short distance ahead of the fire where they may or may not start new fires before the main fire front overruns them. There are, at present, no techniques for accounting for the effect of short-range spotting on fire behavior. The deficiency does not appear to be a problem in predicting fire behavior. Short-range firebrands must ignite the fuel and start a new fire front before the fire overruns that position or the spotting will not be significant in increasing spread rate. In many cases the main fire does overrun the potential spot fires. Further, the model assumes that fuels are uniform and continuous. Short-range spotting can actually compensate for the discontinuous nature of some fuels, giving extended usefulness of the model.

The difference between short-range and long-range spotting is not so much defined by distance as it is by whether or not the firebrands are being lofted by a convection column and carried beyond the immediate area that is being heated and that will soon be overrun by the fire.

Long-range spotting.—As the name implies, the embers are carried well beyond the fireline where new fires are started that for some time grow and spread independent of the originating fire. There are two ways that embers can travel beyond the fire front.

1. They can be carried aloft by strong convective currents where they are caught in the prevailing wind and begin to fall. Firebrands can be lofted by one or more trees torching out, by a concentration of ground fuels that produces enough vertical velocity to loft a firebrand, or by a fire whirl. Low density particles with high drag will travel the greatest distance, but may burn out before reaching the ground.

2. Firebrands, some very large, can be picked up and suspended in a fire whirl that then moves out of the fire area. On the Flambeau experimental fire in 1967 a firebrand 3 inches in diameter and 3 ft long that had been lifted by a strong fire whirl landed near the author. The flame within the whirl extinguishes, but the whirl continues to move downwind similar to a dust devil. The glowing firebrands are carried in a central core and are deposited as the whirl loses energy. This phenomenon was apparent on the Sundance Fire as reported by Anderson (1968), Berlad and Lee (1968), and Lee (1972).

There is no index for the onset of spotting other than its association with severe fire intensity, torching, crowning, and fire whirls. The conditions that favor the development of fire whirls are discussed in an excellent guide for field applications by Countryman (1971).

Spot fire distance.—Albini (1979) has developed a model for predicting the distance a firebrand will travel. It applies to firebrands originating from torching of a tree. It was not meant to apply to firebrands resulting from a running crown fire or conflagration, but may be considered as a first approximation in such situations. Methods for manually predicting spot fire distance are given below. More recently Albini (1981) has extended the model to include firebrands arising from piled fuel, a heavy concentration of surface fuels, or from several torching trees. Chase (1981) has developed a spot fire distance program for the TI-59 utilizing Albini's model.

On the Lily Lake Fire (Bear River Ranger District, Wasatch National Forest), frequent intermediate-range spotting from torching lodgepole pine afforded two opportunities to test the spotting model in its new form for the TI-59 calculator (letter by Frank Albini on file at the Northern Forest Fire Laboratory).

Test results for spotting distance (miles):

Case	Model high estimate	Model low estimate	Midrange of model estimate	Reconstruction of actual spotting distance
1	1.32	0.97	1.04	0.76
2	.91	.40	.64	.75

A simplified manual calculation is presented here.[5]

Limitations:

1. The source of firebrands is from a single torching tree (see footnote 6).
2. The terrain is level.
3. The firebrand is assumed to **travel over forested** terrain.
4. The method requires data about the branching structure of the torching tree's species. These data were used to construct the nomograms used to predict lofting height of the firebrand. Similarity between tree species can be used to extend the method to other species.

[5]These simplified procedures were originally developed from Albini's work by Hal Anderson and later improved by Pat Andrews at the Northern Forest Fire Laboratory. If you have a TI-59 calculator, obtain Chase's paper for a more comprehensive method. To obtain a copy of the program, send 7 blank magnetic strips for a TI-59 calculator to the Northern Forest Fire Laboratory, Drawer G, Missoula, MT 59806, and request the spotting distance program.

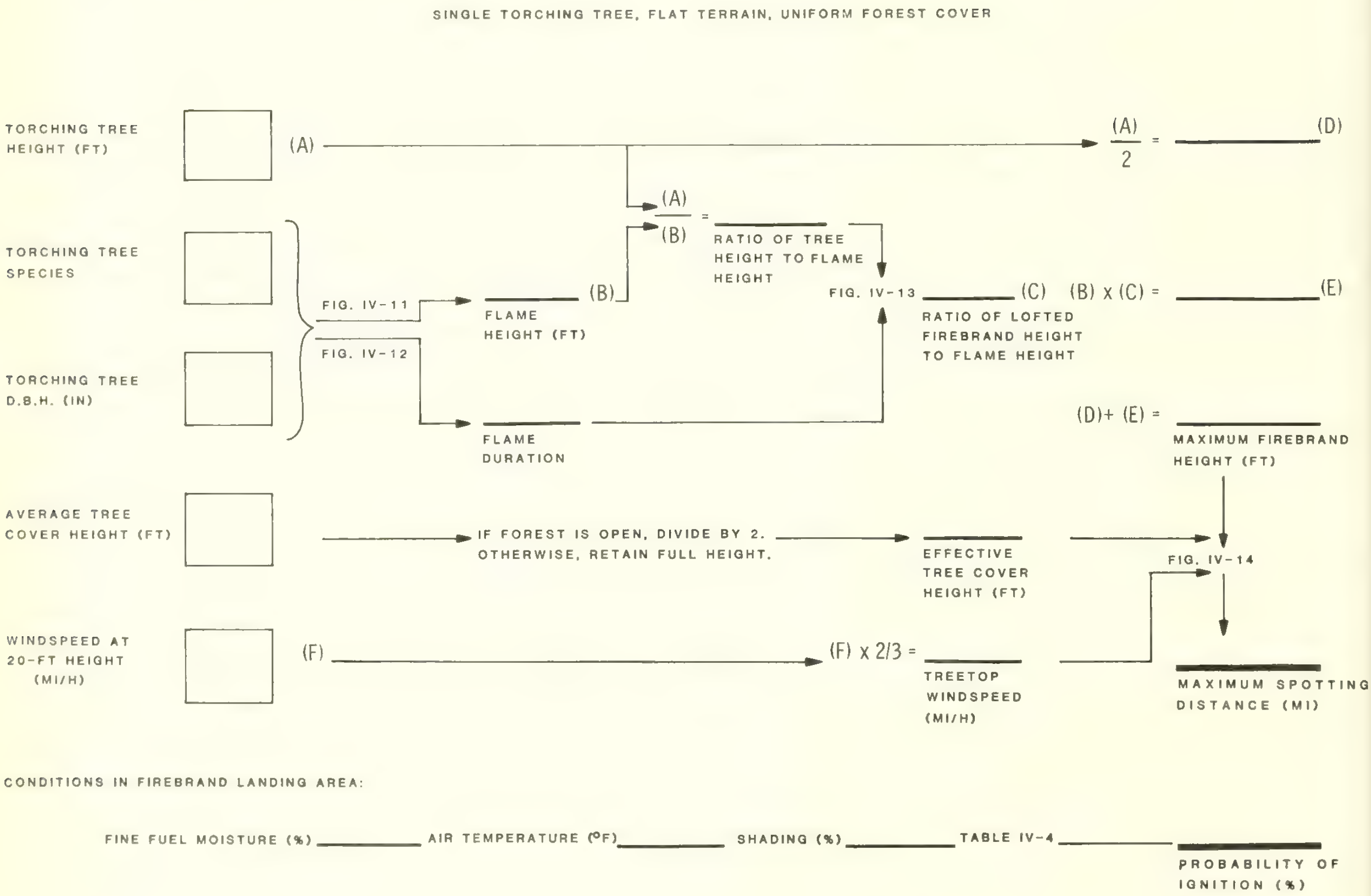
Procedures:

Calculation of spot fire distance requires the following information:

1. Name of tree species that is torching.
2. Height of torching tree (feet).
3. Diameter at breast height (d.b.h.) of torching trees (inches).
4. Average treetop height along the path of the firebrand (feet). The average treetop height is intended to characterize the general forest cover of the terrain as it influences the wind field that will transport the firebrand. If the area has broken forest cover, use half the treetop height.
5. Windspeed as measured in an open area 20 ft above the vegetation (mi/h).

A worksheet for calculating maximum spotting distance is shown as exhibit IV-1. The inputs are entered in the boxes.

Exhibit IV-1.—Spotting worksheet.



The worksheet is completed by extracting data from figures IV-11 through IV-14 as you proceed across the worksheet from left to right.

After entering the inputs, obtain flame height from figure IV-11, using d.b.h. and torching tree species.[6] Enter flame height on the worksheet.

Obtain duration from figure IV-12, using d.b.h. and tree species and record on the data sheet.

Divide the tree height by the flame height and enter on the worksheet as the ratio of tree height to flame height.

Obtain the ratio of lofted firebrand height to flame height from figure IV-13, using flame duration and ratio of tree height to flame height as inputs.

Note that these entries are identified by a capital letter in parenthesis.

Divide (A) by 2 to obtain (D).

Multiply (B) by (C) to obtain (E).

Add (D) and (E) to obtain the maximum firebrand height, feet.

If the forest cover downwind from the torching tree is a relatively open stand, divide the average tree cover height by 2; otherwise use the full tree height.

Multiply the 20-ft windspeed (F) by two-thirds or 0.667 to obtain the treetop windspeed (mi/h).

On the lower right-hand edge of figure IV-14, locate the firebrand height. Proceed vertically to the effective tree cover height. Move left horizontally until you reach the treetop windspeed. Move vertically down to the bottom axis and read the maximum spot fire distance. Record this on the data sheet.

A worked example follows.

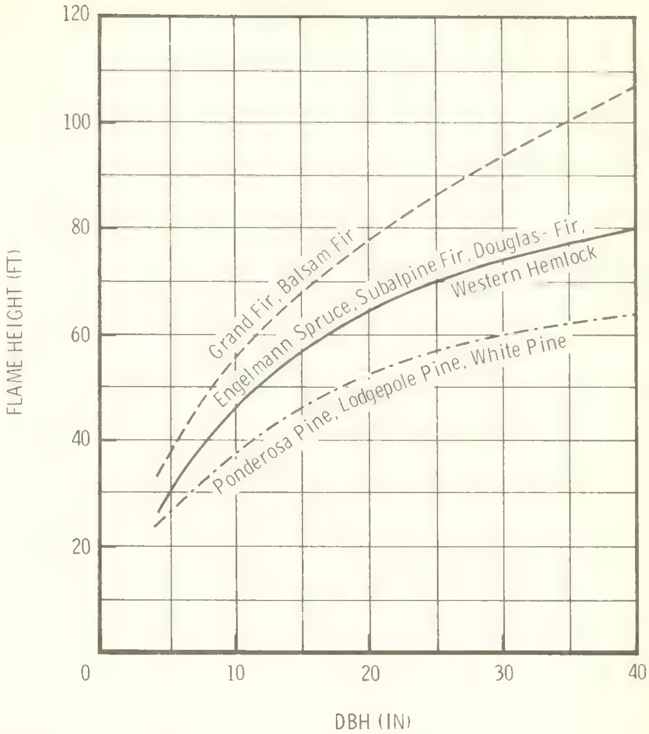


Figure IV-11.—Flame height produced by torching tree.

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[6]The TI-59 program (Chase 1981) corrects flame height and flame duration to account for the simultaneous torching of groups of trees.

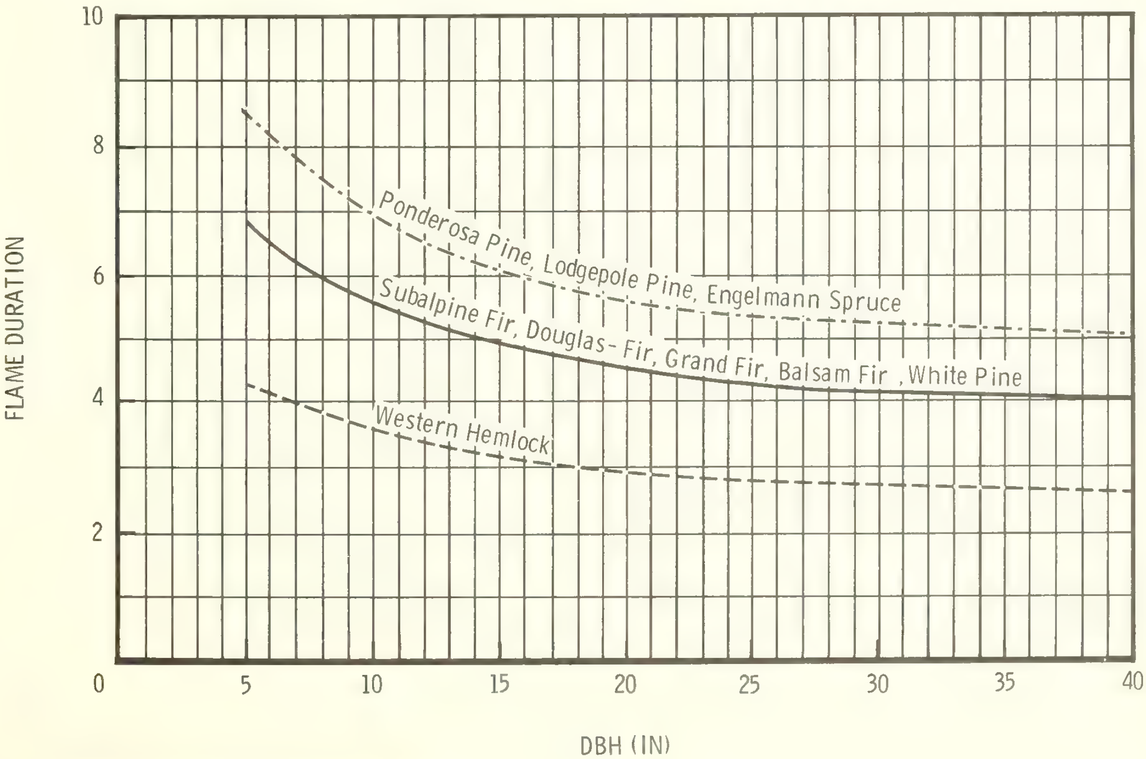


Figure IV-12.—Flame duration (dimensionless) of torching tree.

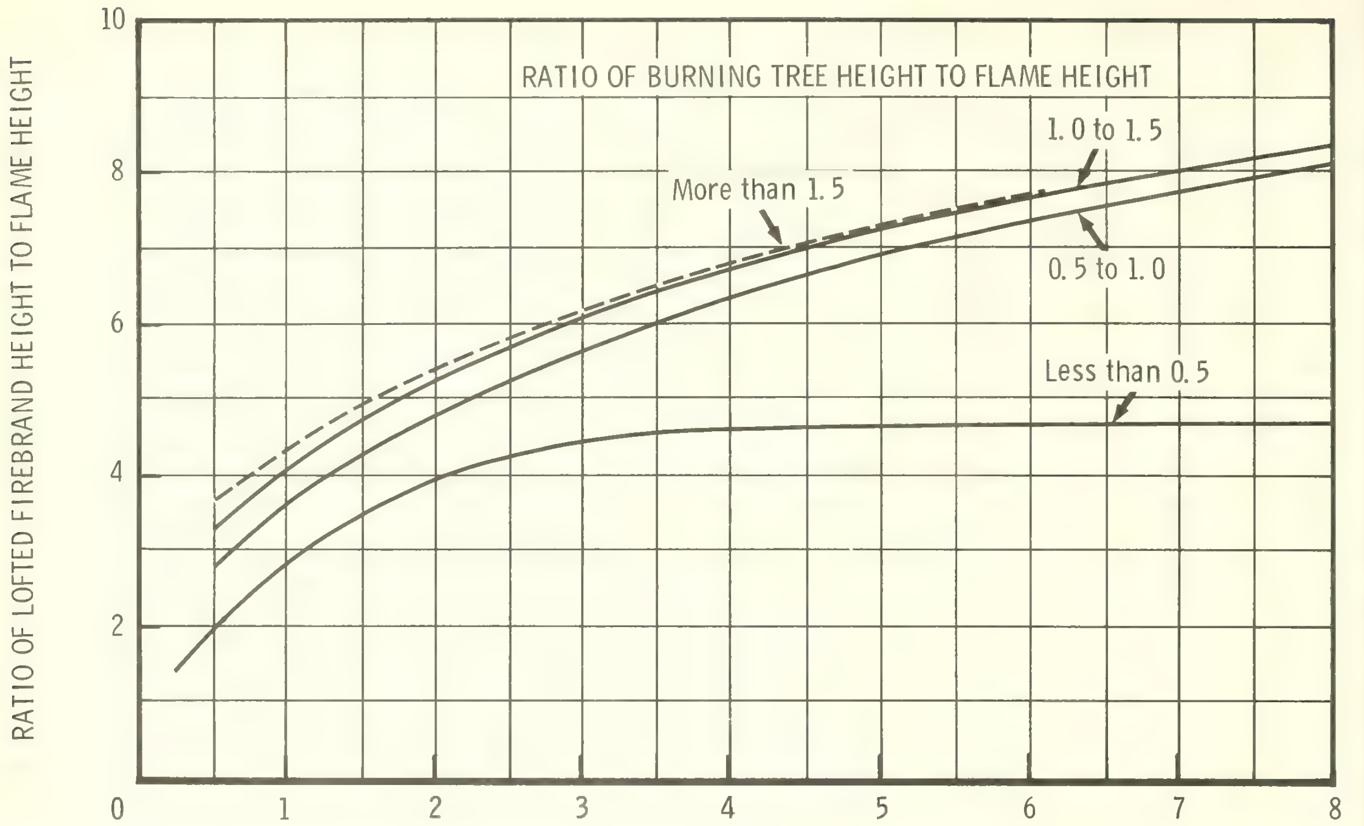


Figure IV-13.—Ratio of lofted firebrand height to flame height.

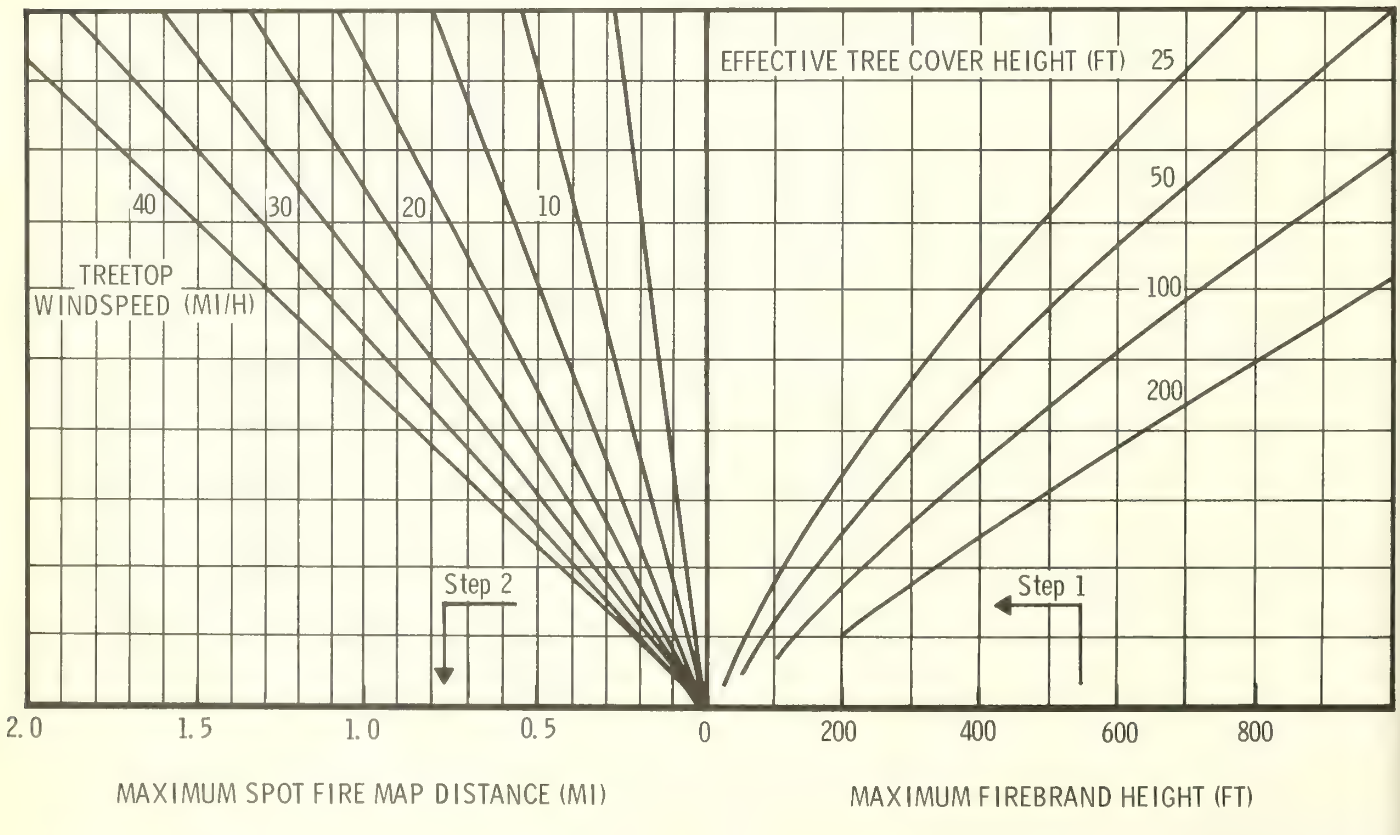
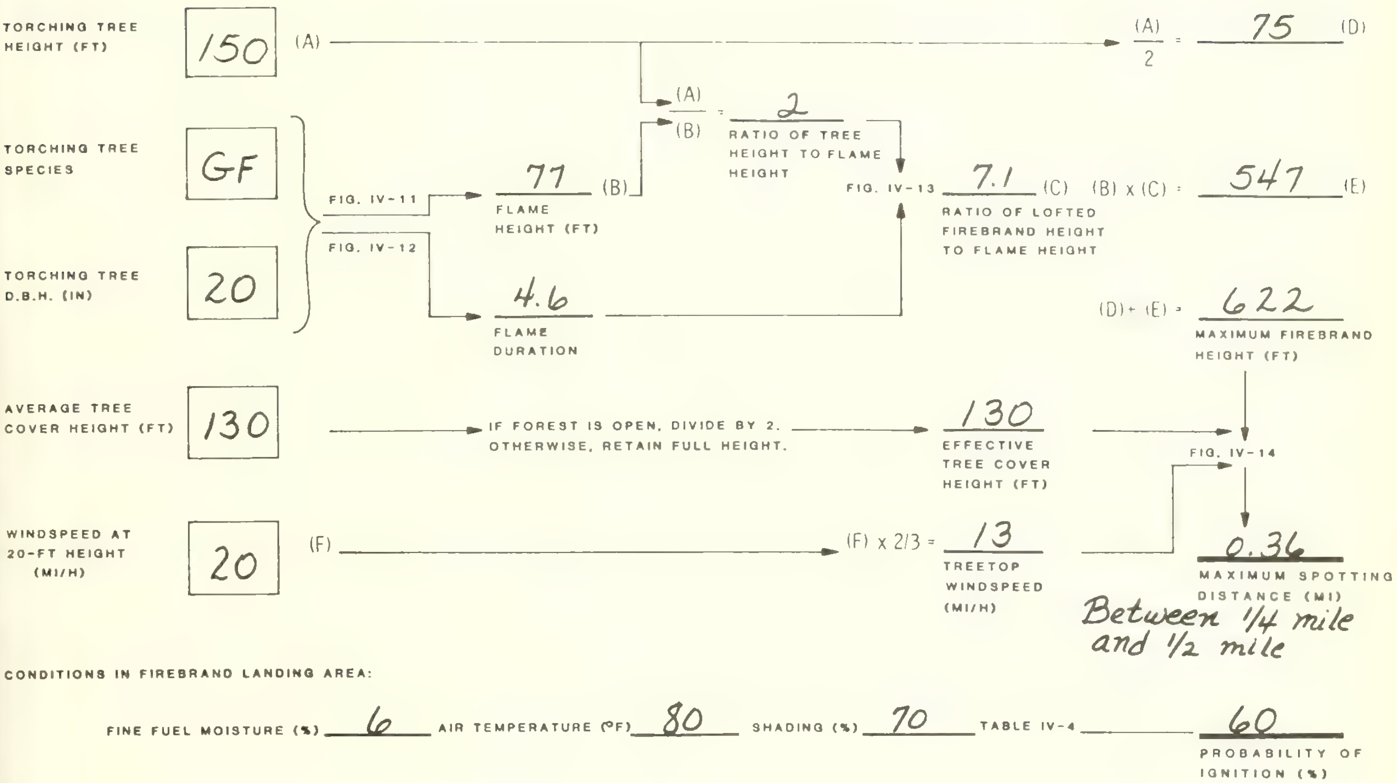


Figure IV-14.—Maximum spot fire distance nomogram.

SINGLE TORCHING TREE, FLAT TERRAIN, UNIFORM FOREST COVER



PROBABILITY OF IGNITION

When spotting is possible, the probability of ignition where the firebrand lands must also be considered. The method presented here was developed by Mark J. Schroeder (unpublished office report 2106-1, August 13, 1969), and adapted for FBO's by Pat Andrews. It is based on the amount of heat required to bring the fuel to ignition temperature. It assumes that the firebrand lands on **fine** fuel. The probability of ignition does not consider whether or not the resulting ignition will be sustained and therefore is different from ignition component.

Probability of ignition is obtained from table IV-4. The inputs needed are:

- fine fuel moisture.
- air temperature.
- percent shading of ground fuels due to either cloud cover or tree canopy.

A place for recording this information is given on the bottom of the spotting worksheet, exhibit IV-1.

Example: fine dead fuel moisture = 6%
shading due to tree canopy = 100%
air temperature under canopy = 75° F
from table IV-4: probability of ignition = 50%

Table IV-4.— Probability of ignition (Percent)

		Fine dead fuel moisture (percent)															
Shading	Dry bulb temp	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Percent	*°F*																
0-10	110+	100	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	70-79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
10-50	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	100	80	70	60	50	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
60-90	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	70	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
100	110+	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	90-99	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
	30-39	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10	10

CROWNING

An excellent source of background information on crown fires is given by Van Wagner (1977) who groups crown fires into 3 classes:

Passive crown fires; those in which trees torch as individuals, reinforcing the spread rate, but are not basically different from surface fires. **Active crown fires**; those in which a solid flame develops in the crowns, but the surface and crown phases advance as a linked unit dependent on each other. **Independent crown fires**; those in which the fire advances in the crowns alone.

The conditions under which crown fires are likely to occur were identified in table IV-1 as those that will produce fireline intensities in surface fires beginning in the 500 to 1,000 Btu/ft/s range. This usually requires hot and dry conditions with strong winds or steep slopes. It also requires an overstory that is conducive to carrying or sustaining a crown fire.

Following his attendance at the 1979 FBO course, Alexander[7] produced a set of graphs and tables that relate the critical surface intensity for crown combustion and flame length to the height of the live crown base and the crown foliar moisture content. Although I have no experience with these graphs, they appear to be reasonable, and one is presented in appendix F.

Fahnestock (1970) produced a key (exhibit IV-2) that identifies the nature of ladder fuels spacing and general tree crown characteristics that are inducive to crown fires. The key produces a value between 0 and 10. The output numbers indicate the **order** of likelihood of a sustained crown fire and are not to be construed as a proportionality nor as a probability (Fahnestock 1970).

[7]Martin E. Alexander, fire research officer, Canadian Forestry Service, Northern Forest Research Centre, 5320 – 122 St., Edmonton, Alberta T6H 3S5 Canada.

Exhibit IV-2.—Fahnestock's Crowning Potential Key.

	Rating
A. Foliage present, trees living or dead—B	
B. Foliage living—C	
C. Leaves deciduous or, if evergreen, usually soft, pliant, and moist; never oily, waxy, or resinous (1)	0*
CC. Leaves evergreen, not as above—D	
D. Foliage resinous, waxy, or oily—E	
E. Crowns dense—F	
F. Ladder fuels plentiful—G	
G. Canopy closure > 75 percent (2)	9
GG. Canopy closure less (3)	7
FF. Ladder fuels sparse or absent—H	
H. Canopy closure > 75 percent (4)	7
HH. Canopy closure less (5)	5
EE. Crowns open—I	
I. Ladder fuel plentiful (6)	4
II. Ladder fuels sparse or absent (7)	2
DD. Foliage not resinous, waxy, or oily—J	
J. Crowns dense—K	
K. Ladder fuels plentiful—L	
L. Canopy closure > 75 percent (8)	7
LL. Canopy closure less (9)	4
KK. Ladder fuels sparse or absent—M	
M. Canopy closure > 75 percent (10)	5
MM. Canopy closure less (11)	3
JJ. Crowns open—N	
N. Ladder fuels plentiful (12)	3
NN. Ladder fuels sparse or absent (13)	1
BB. Foliage dead—O	
O. Crowns dense—P	
P. Ladder fuels plentiful—Q	
Q. Canopy closure > 75 percent (14)	10
QQ. Canopy closure less (15)	9
PP. Ladder fuels sparse or absent—R	
R. Canopy closure > 75 percent (16)	8
RR. Canopy closure less (17)	4
OO. Crowns open—S	
S. Ladder fuels plentiful (18)	6
SS. Ladder fuels sparse or absent (19)	2
AA. Foliage absent, trees dead—T	
T. Average distance between trees 33 feet or less—U	
U. Ladder fuels plentiful—V	
V. Trees with shaggy bark and/or abundant tinder (20)	10
VV. Trees not as above (21)	8
UU. Ladder fuels sparse or absent—W	
W. Trees with shaggy bark and/or abundant tinder (22)	10
WW. Trees not as above (23)	5
TT. Average distance between trees > 33 feet (24)	2

*Rare instances have been reported, resulting from extreme drought.

The discussion is directed to crown fires in timber canopies. Brush fields can also carry crown fires, but the fire behavior of brush fields is covered by the methods of this manual for surface fuels.

When conditions are favorable for crowning—strong winds or steep slope, with a closed canopy—fireline intensity should be estimated carefully. Fuel model 8, which represents short needle litter fuels, will never predict an intensity high enough to initiate crowning. Fuel models 9 and 10 can, if the windspeed is strong enough. Therefore, consider the choice of a wind adjustment factor carefully. Do not assume fully sheltered conditions without regard to openings, or ridgetops where the fuels may be fully exposed and the fireline intensity can flare up if only for a short time, but sufficient to induce a crown fire.

Similarly, if there are jackpots of dead and down fuel scattered under the canopy, these can induce flareups and crown fires. The jackpots of fuel may be better described by a slash model, such as 12 or 13, than a timber model. See the two-fuel-model concept for this calculation.

The rate of crown fire spread cannot be predicted directly from a model at this time. On the Sundance Fire it was measured by two men in a pickup truck driving parallel to the crown fire at 6 mi/h or 480 chains/h. The rate can be calibrated against spread in surface fuels. Comparison with fuel model 10 on level or gently rolling terrain (Pattee Canyon Fire 1977; Lily Lake Fire 1980)[8] has shown spread rate to be 2 to 4 times faster in the crowns than was calculated for fuel model 10 with the fuel considered to be fully exposed to the wind (wind correction factor 0.4). Short runs up steep slopes have produced faster runs, eight times the predicted rate with model 10.[9]

Crowning on the Lily Lake Fire

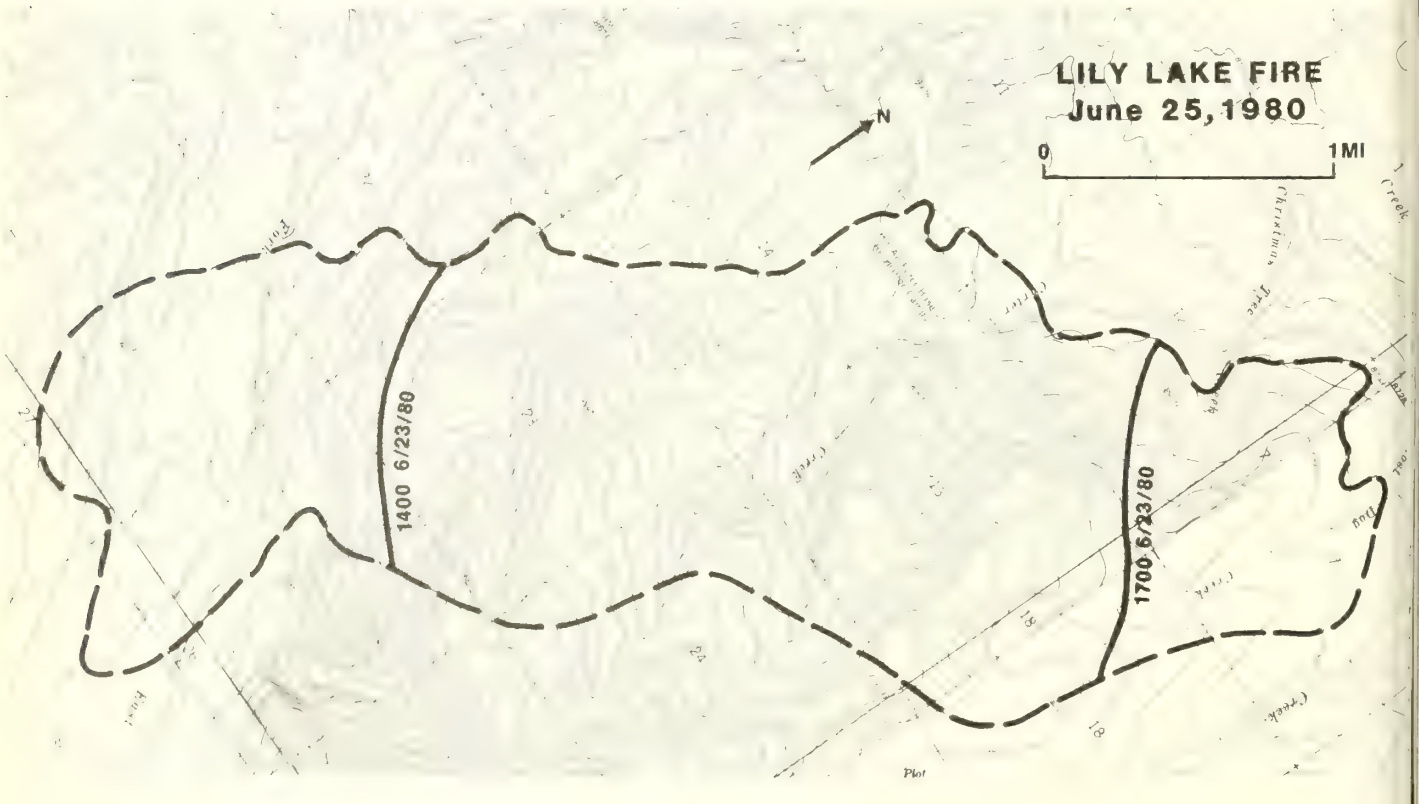
The Lily Lake Fire on the Wasatch National Forest made a strong initial run by crowning through lodgepole pine on the afternoon of June 23, 1980. The approximate time and location of the fire as well as the weather data from a nearby guard station provide an excellent chance to compare the crown fire rate of spread with a predicted rate of spread in surface fuels under the same conditions.

The fire started from an escaped campfire in the early afternoon of June 23, 1980. The fire made a short run to the top of a nearby ridge where it spotted across the East Fork of the Bear River, a distance of approximately 1 mile; at that point it began a run to the northeast corner of Section 33 near Christmas Tree Creek. It was generally paralleling the contours of nearby mountains, although it crossed three minor drainages and several low ridges during this period (see map). Minimum elevation of the fire is about 8,600 ft and the maximum about 9,500 ft.

Examination of the area from the air and on the ground reveals a very severe crown fire, with the trees completely bare

[8]Data on file, Northern Forest Fire Laboratory. See example at end of this section.

[9]Personal communication with George Rinehart, Ship Island Creek Fire, 1979.



of foliage. Surface fuels were consumed, but evidence indicated that the fire burned most intensely in the crowns.

There had been no rain in this part of the country since June 5. Strong southwesterly winds were blowing from 35 to 40 miles an hour across the ridges. Wind persisted for several days after the fire began.

Data from the fire weather station at the nearby Bear River Guard Station were as follows:

State of weather	1
Dew point temperature	21° F
Dry bulb temperature	69° F
Relative humidity	16%
Wind, south	20 mi/h
Fuel moisture sticks	4%
T_{max} for previous 24 hours	78° F
T_{min}	46° F
RH_{max}	48%
RH_{min}	12%

Inputs to the fire behavior worksheet were inferred as follows:

		Comments
Fuel model	10	
Shade factor	2	50%-90% shade due to crown cover
Dry bulb temperature	78° F	
Relative humidity	12%	
1-H fuel moisture	5%	obtained from tables for shade
10-H fuel moisture	6%	4 percent measured in open
100-H fuel moisture	7%	estimate
Live fuel moisture	100%	see later comment
20-ft windspeed across ridges	35–40 mi/h	estimate from meteorologist and helicopter pilot
Wind adjustment factor for midflame wind		0.3 on windward slope, 0.4 over ridges
Midflame windspeed	11 and 15 mi/h	
Slope	20%	

The choice of live fuel moisture is a bit of a quandary because of the early season that normally would indicate moist fuels. Snow along the upper edge of the fire indicated that some of the area had just melted free of snow. Examination of the live plants revealed that the dwarf whortleberry was barely leafing out; and the arnica was small and scattered. Since there was little live fuel in the lodgepole where the fire was, the live fuel moisture was set at a nominal value of 100 percent. If the live fuel had been lush and heavy in this area, it would have been set much higher at 200 to 300 percent.

The windspeed across this area was estimated to be 35 to 40 mi/h across the ridges. Wind adjustment factors were estimated for the windward side, going uphill as 0.3 and across the ridges as 0.4. Slopes on the windward side were about 20 percent. There appeared to be considerable dead and down material in unburned areas around the fire; consequently fuel model 10 was chosen.

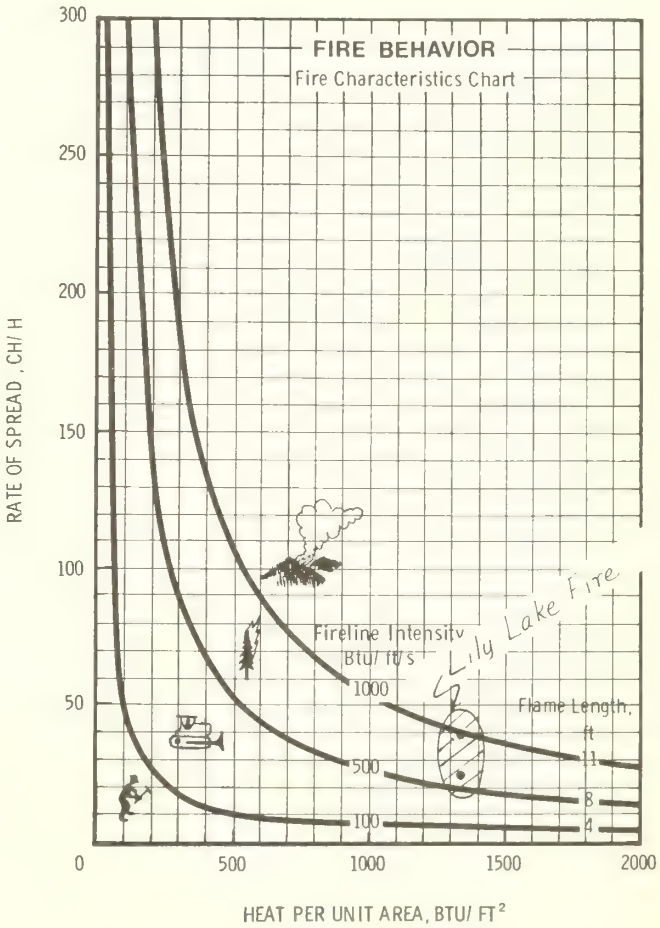
Using the TI-59 calculator, the following fire behavior in surface fuels was calculated:

	Windward slope	Across ridges
Spread rate	26 ch/h	40 ch/h
Heat per unit area	1,324 Btu/ft²	1,324 Btu/ft²
Fireline intensity	641 Btu/ft/s	966 Btu/ft/s
Flame length	9 ft	11 ft

These values are plotted on the accompanying fire characteristics chart.

The chart indicates that a surface fire beneath the crowns would be very intense, with moderate spread rates. Crown torching and spotting are very probable and a running crown fire is possible.

With these large flame lengths accompanied by 30 to 40 mi/h wind, the overstory would almost surely crown, which it did. The measured spread distance between 1400 and 1700 was 2.75 miles, which was covered in 3 hours giving a spread rate of 73.6 ch/h. Comparison of this with the calculated spread rate in the surface fuels (26 to 40 ch/h) shows that the crown fire spread from two to three times faster than what would be predicted in surface fuels (model 10) under the same conditions.



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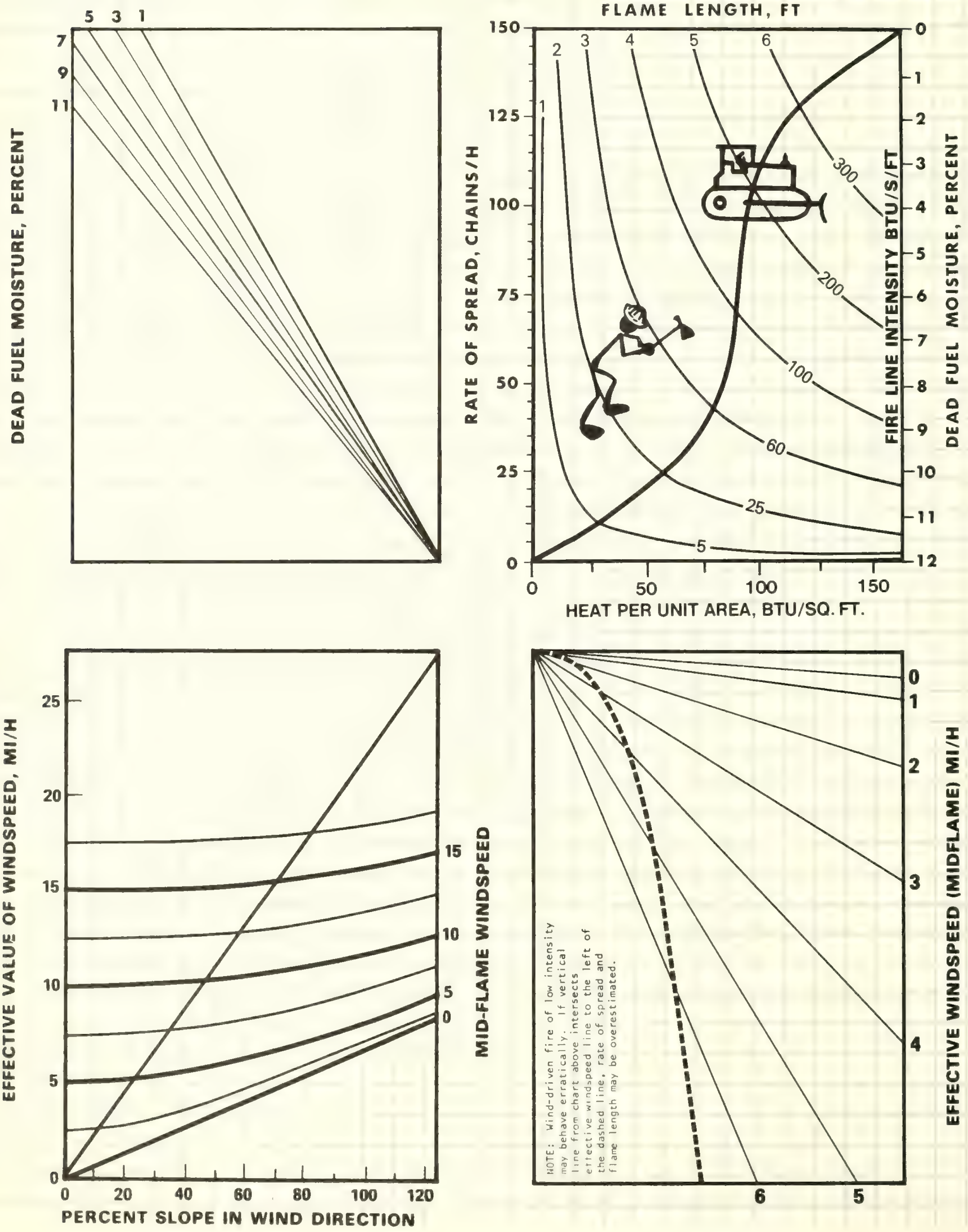
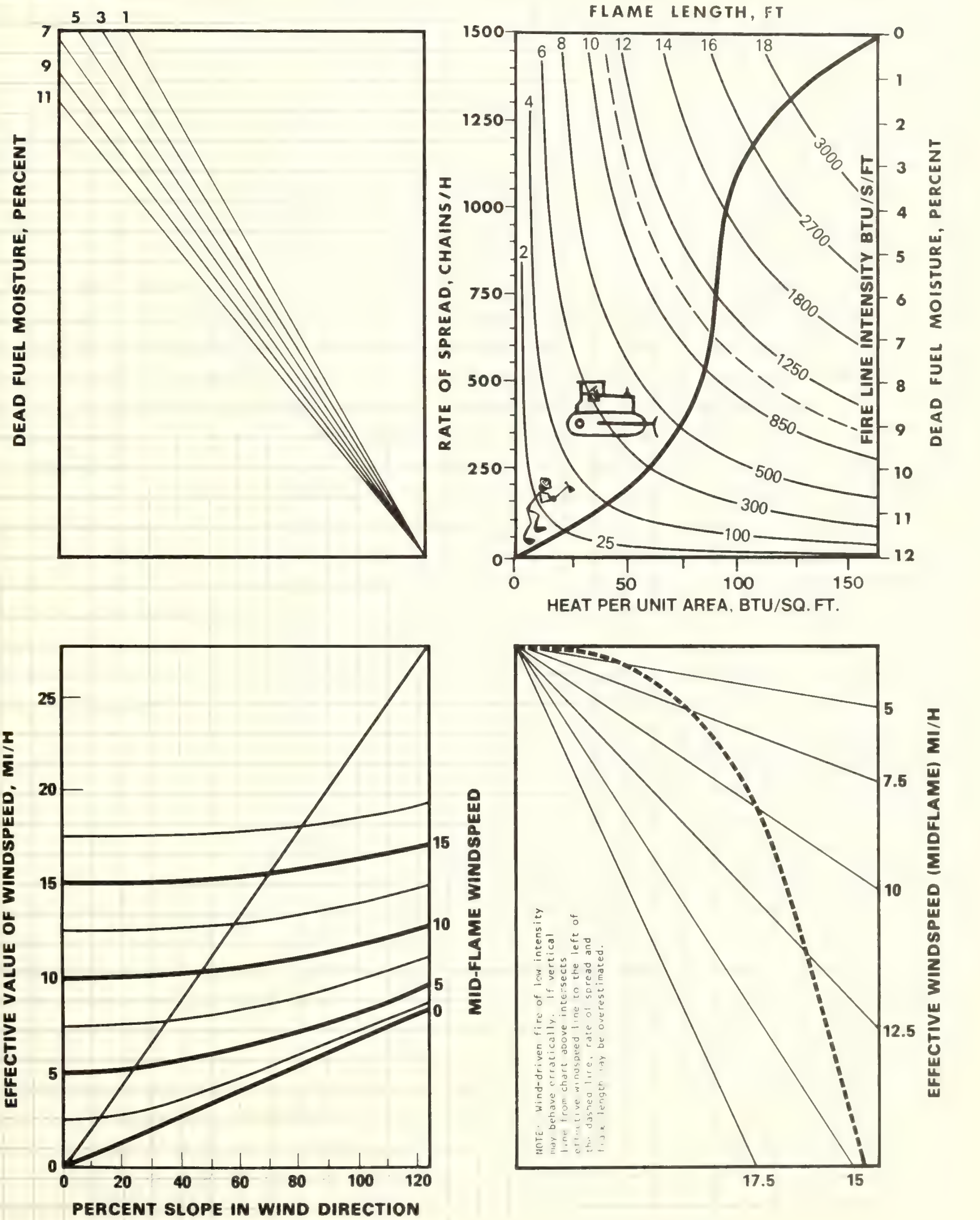
APPENDIX A
Nomograms

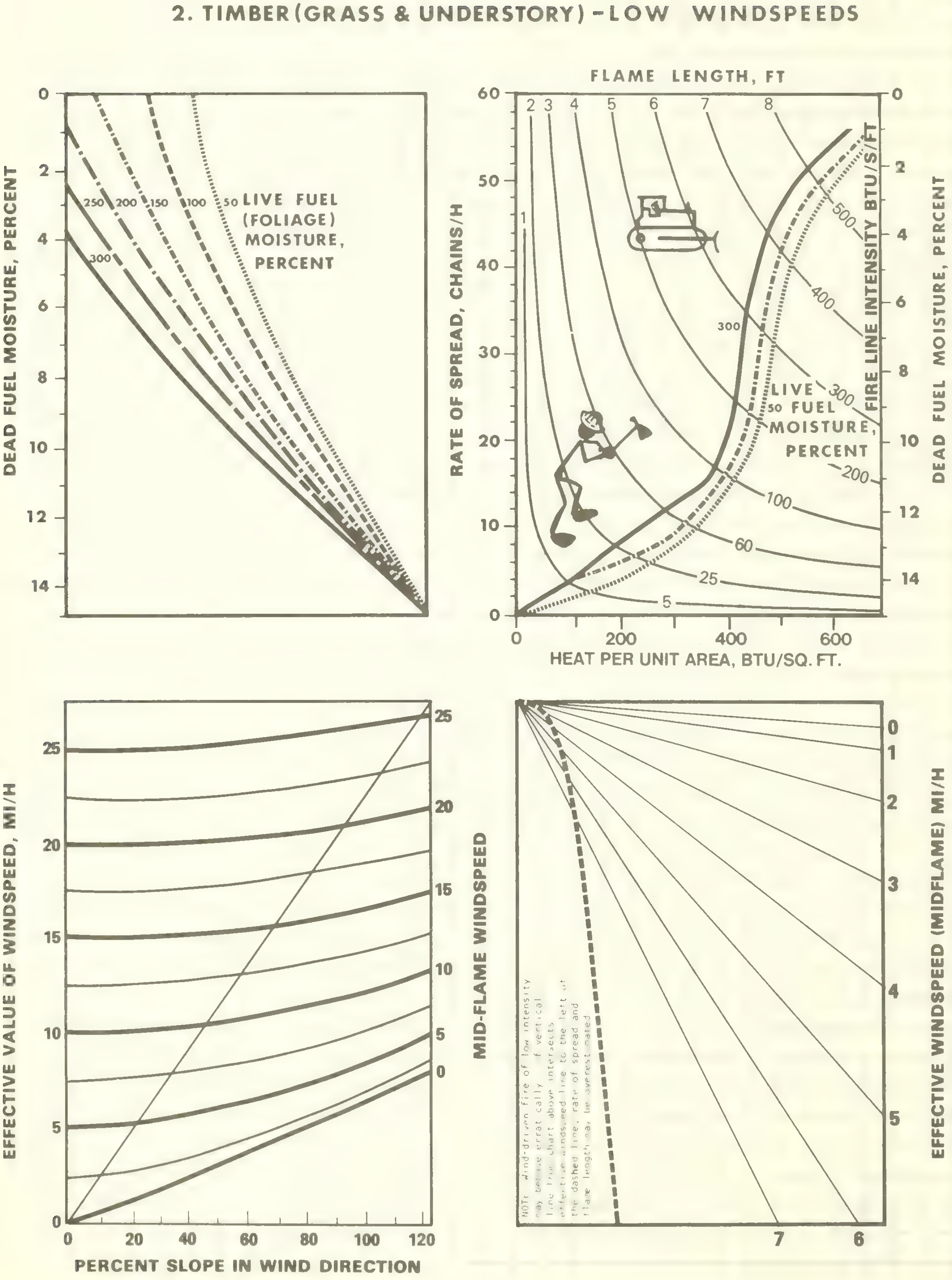
Fuel model 1 – low windspeeds

1. SHORT GRASS (1 FT) –LOW WINDSPEEDS

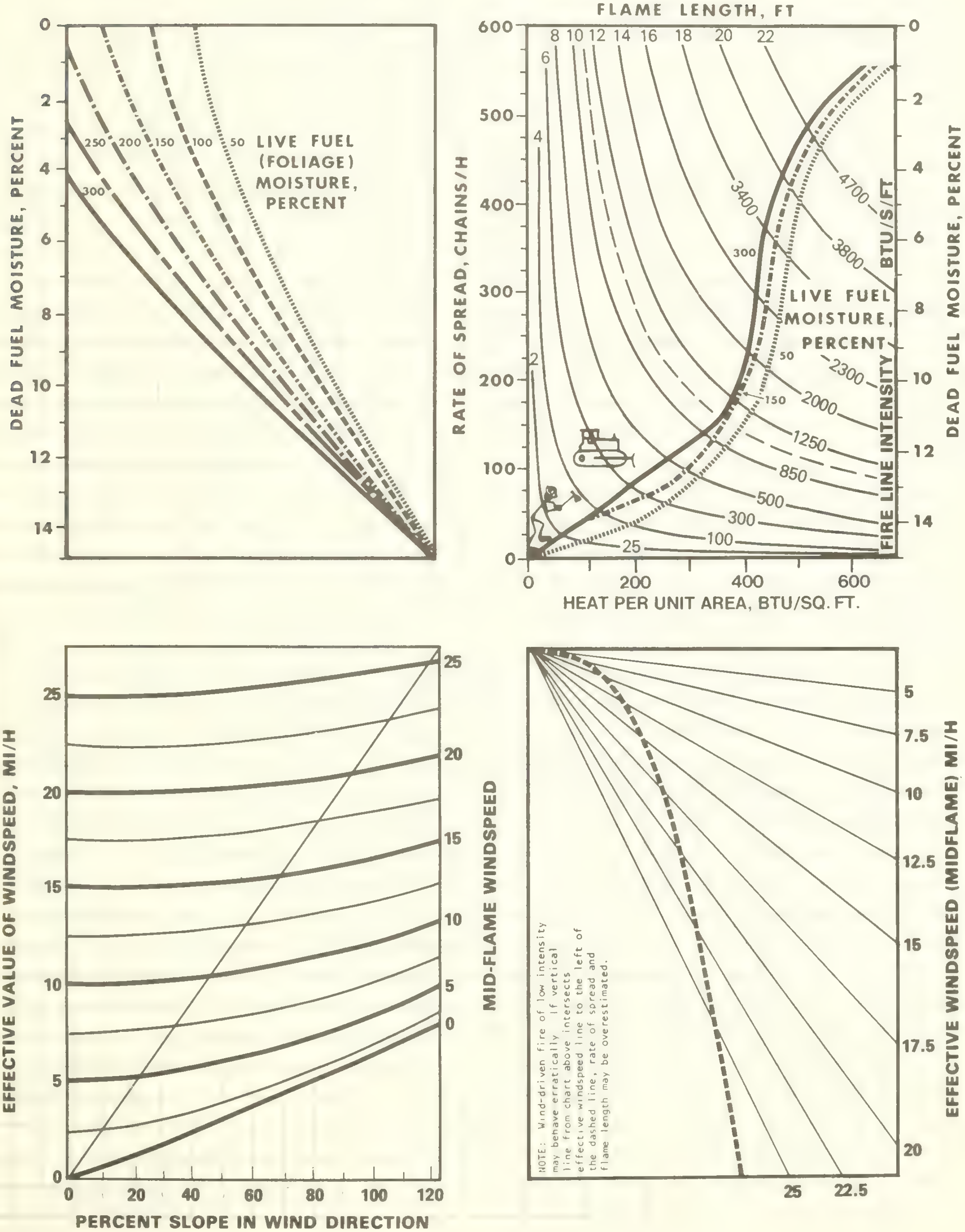


1. SHORT GRASS(1 FT) – HIGH WINDSPEEDS

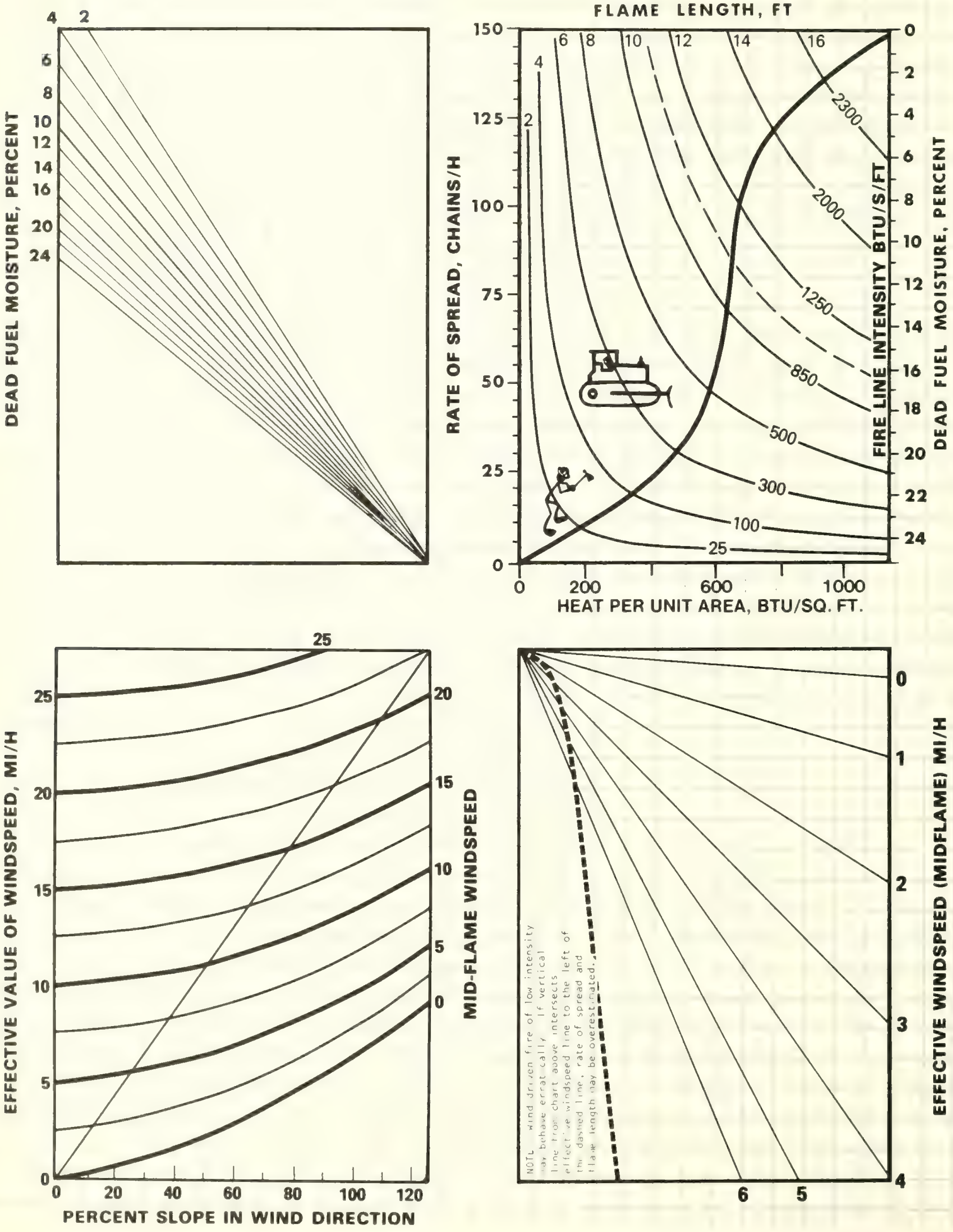



2. TIMBER (GRASS & UNDERSTORY) – LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
300
250
200
150
100
50
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/S/FT
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/SQ. FT.
500
400
300
200
100
60
25
5
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MID-FLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
NOTE: wind-driven fire of low intensity

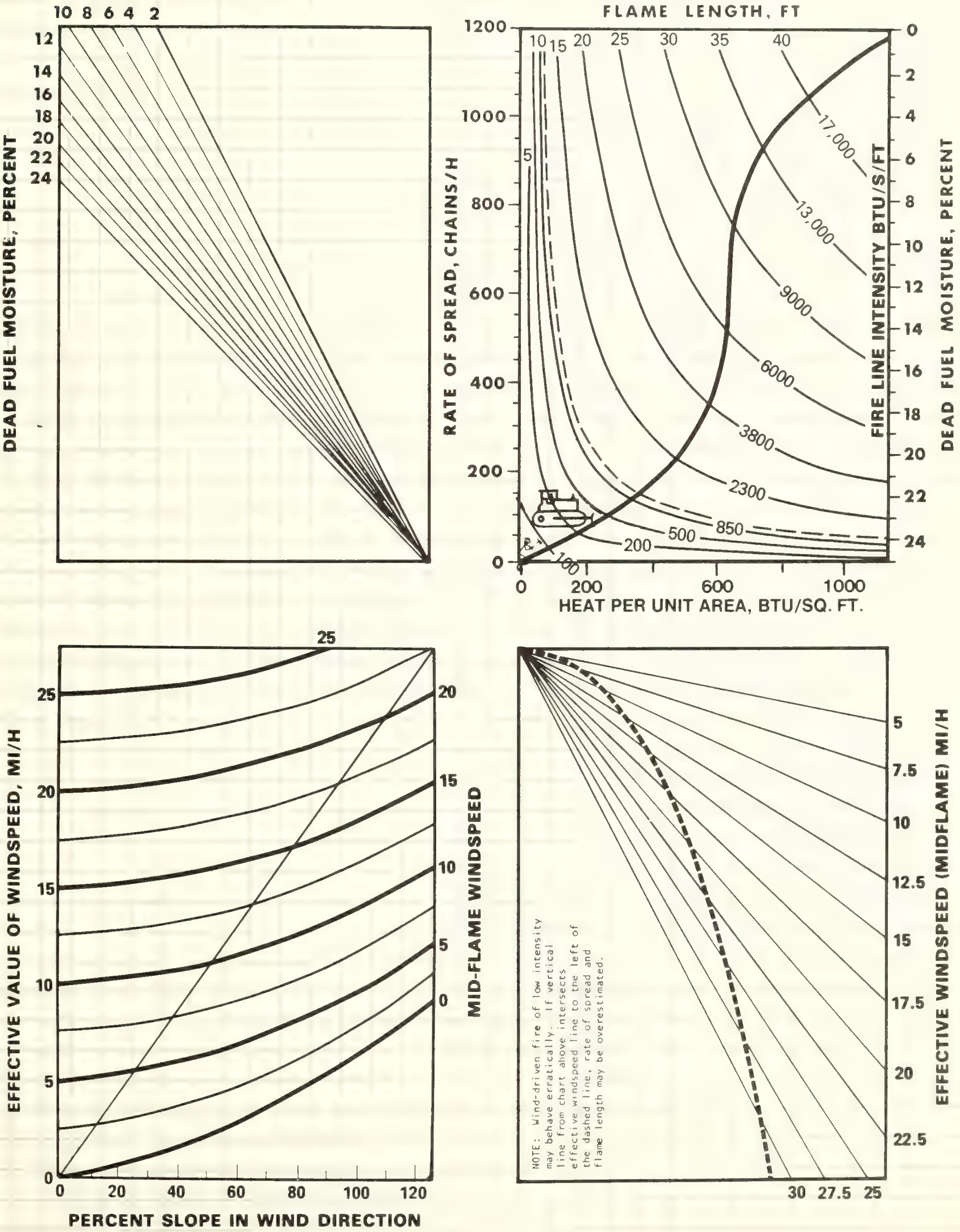
2. TIMBER (GRASS & UNDERSTORY) - HIGH WINDSPEEDS



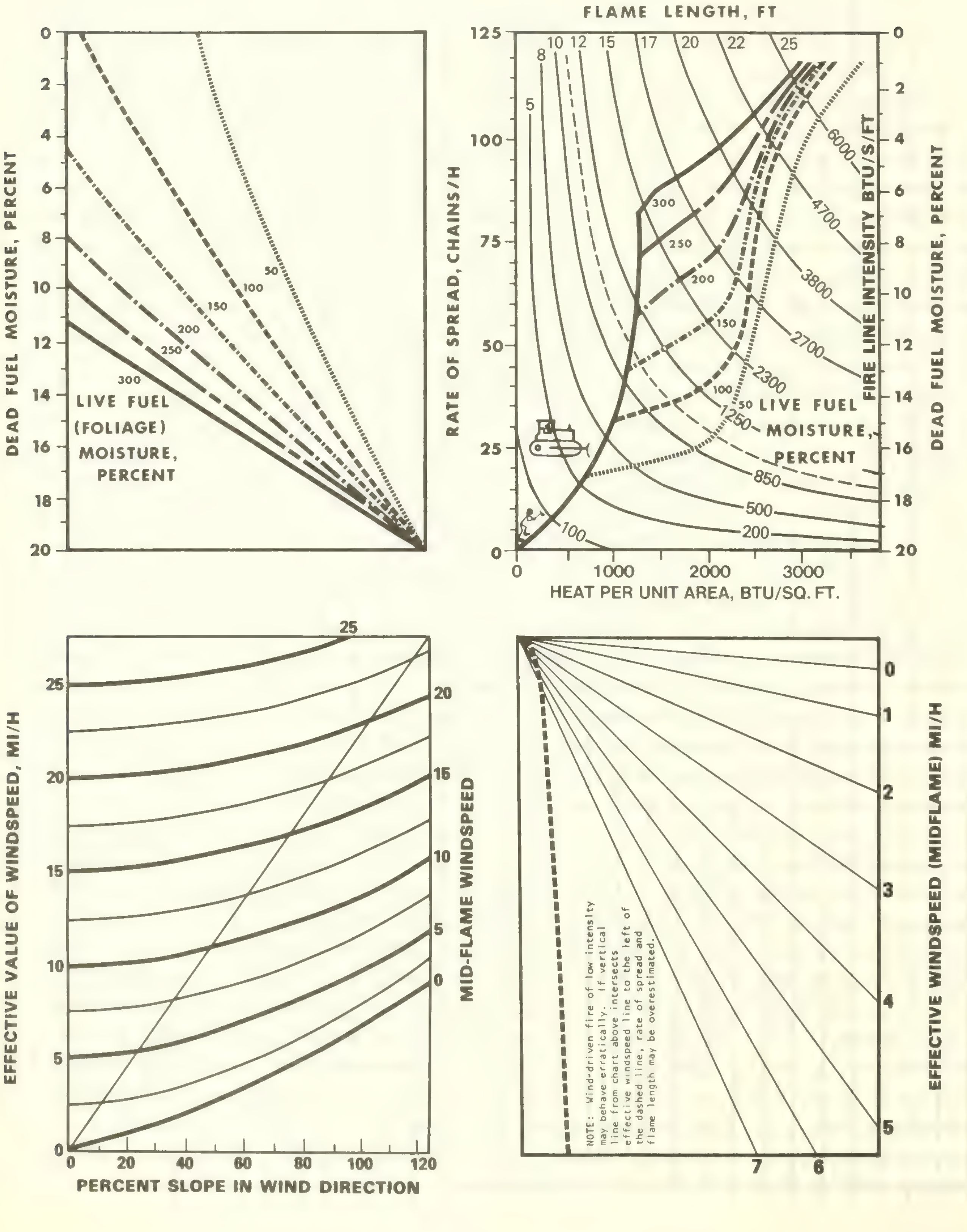
3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS

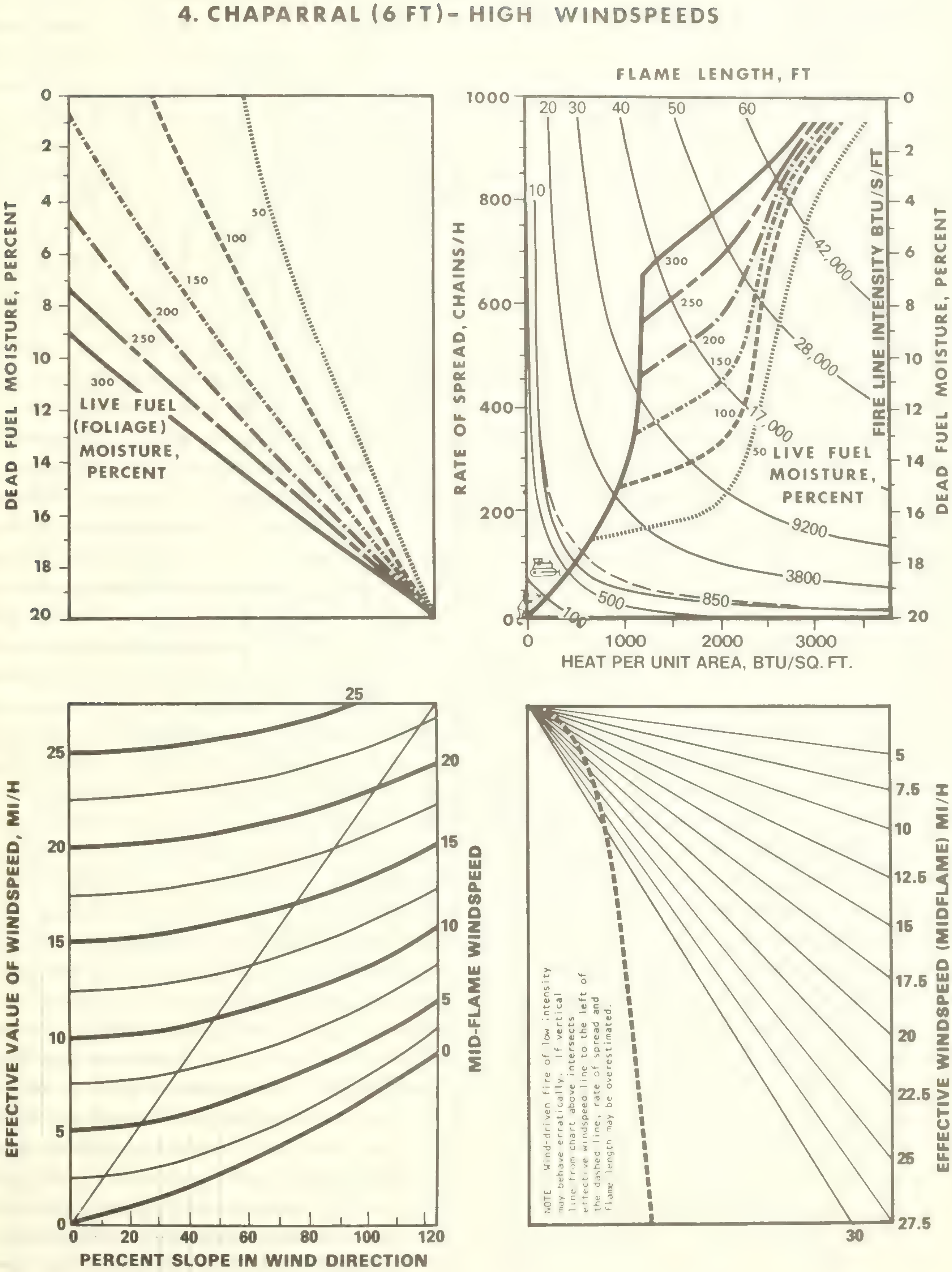


3. TALL GRASS (2.5 FT) - HIGH WINDSPEEDS

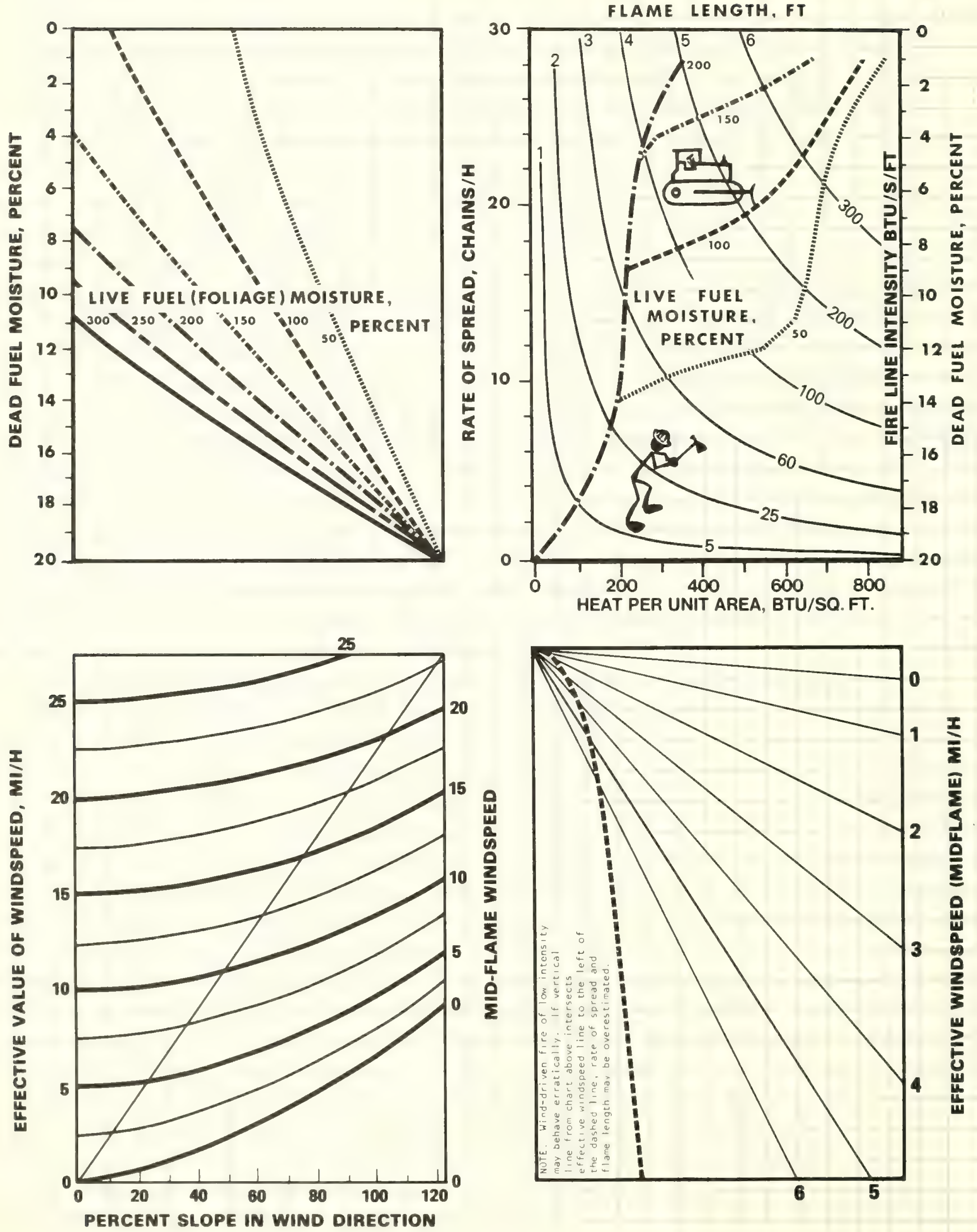


4. CHAPARRAL(6 FT) –LOW WINDSPEEDS

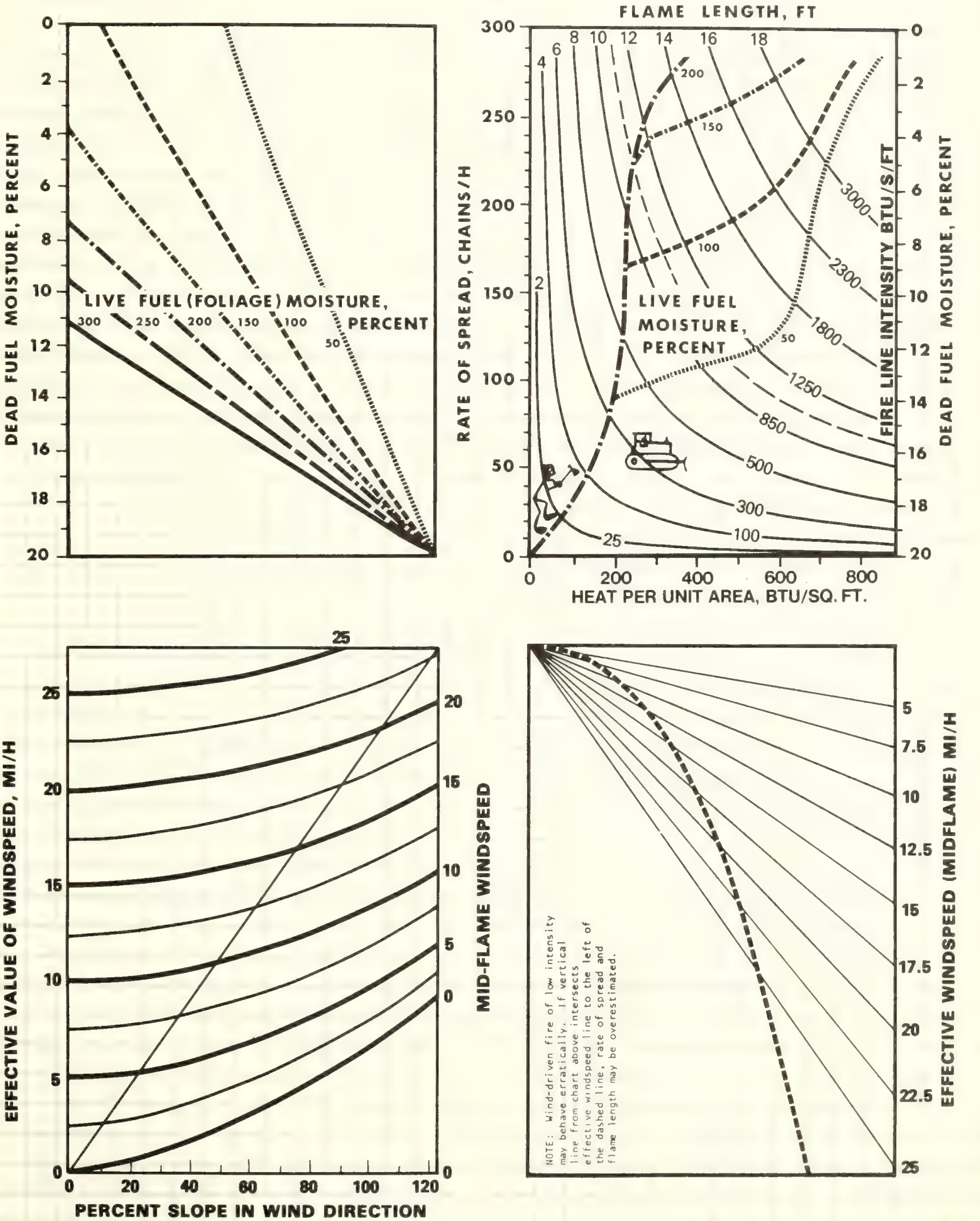



4. CHAPARRAL (6 FT)- HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/S/FT
LIVE FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/SQ. FT.
EFFECTIVE VALUE OF WINDSPEED, MI/H
MID-FLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
NOTE Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

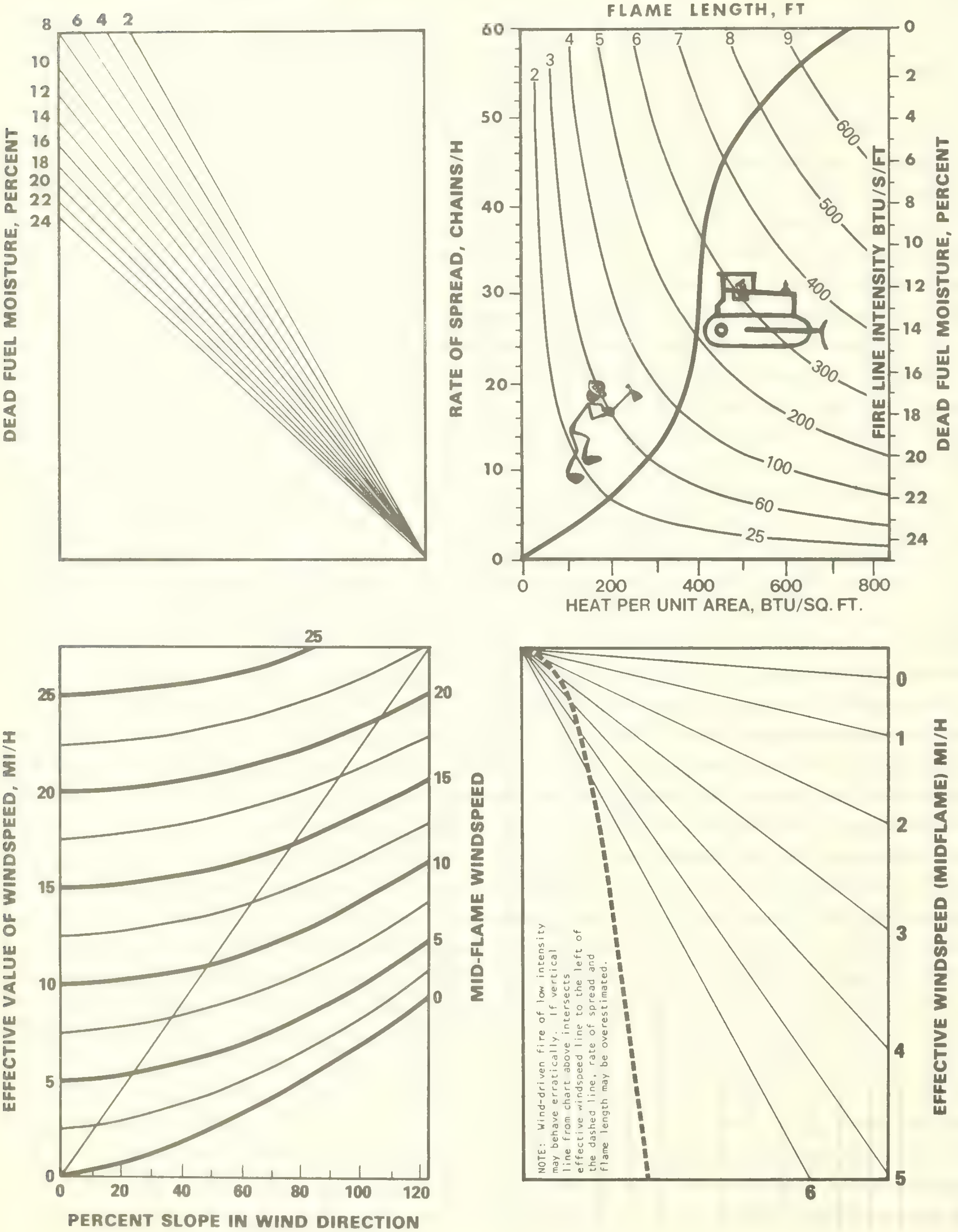
5. BRUSH (2 FT) -LOW WINDSPEEDS



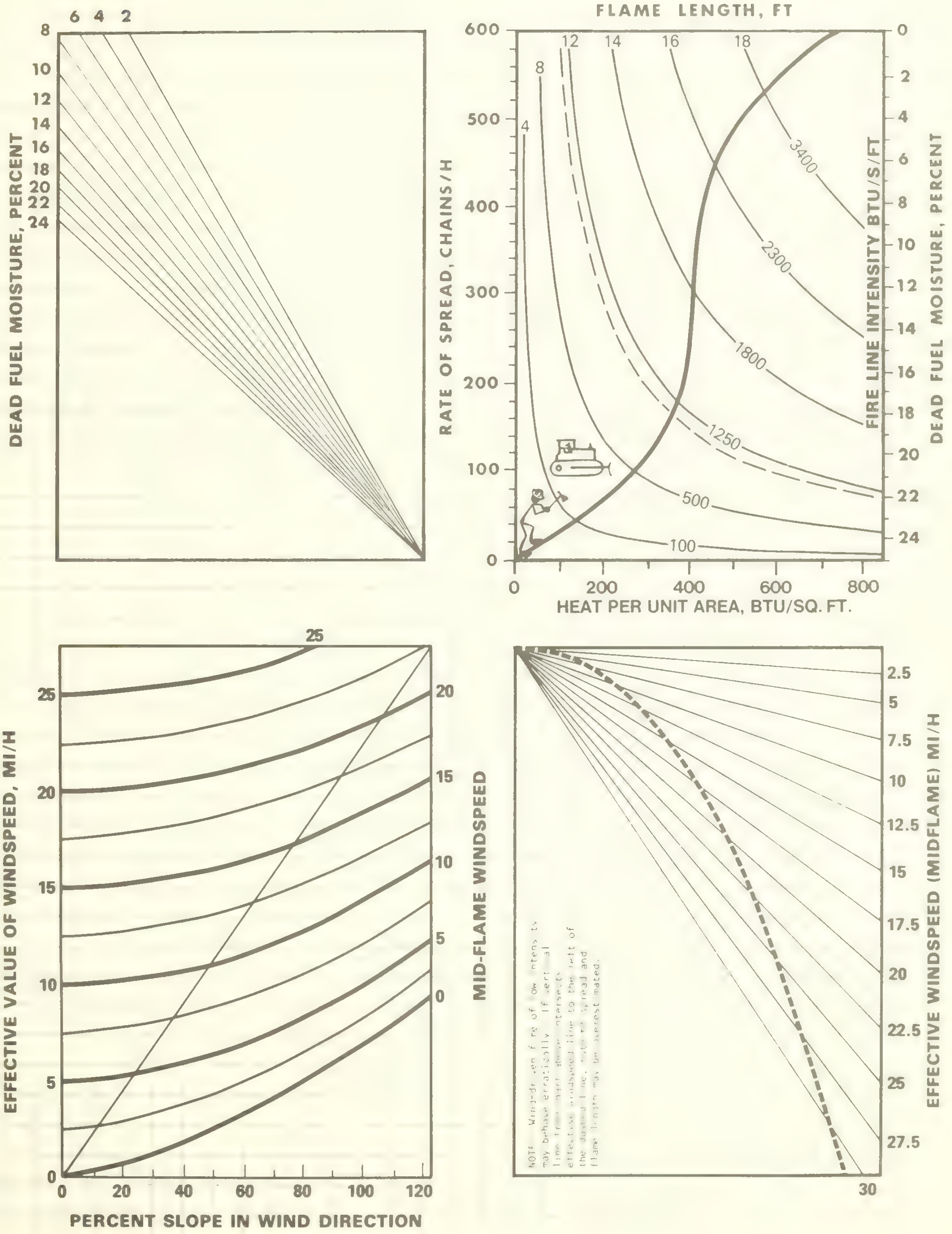
5. BRUSH (2 FT) – HIGH WINDSPEEDS



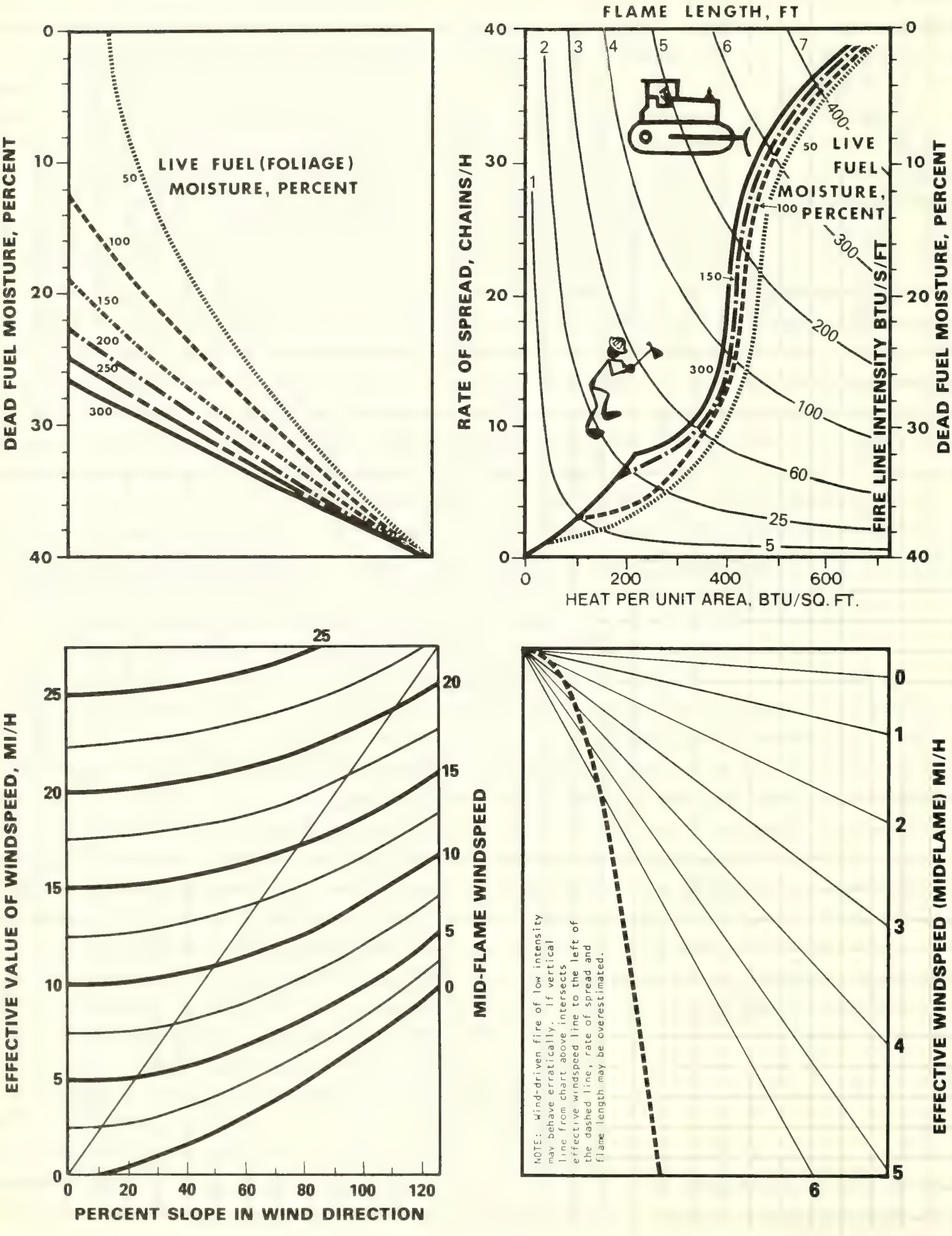
6. DORMANT BRUSH, HARDWOOD SLASH – LOW WINDSPEEDS



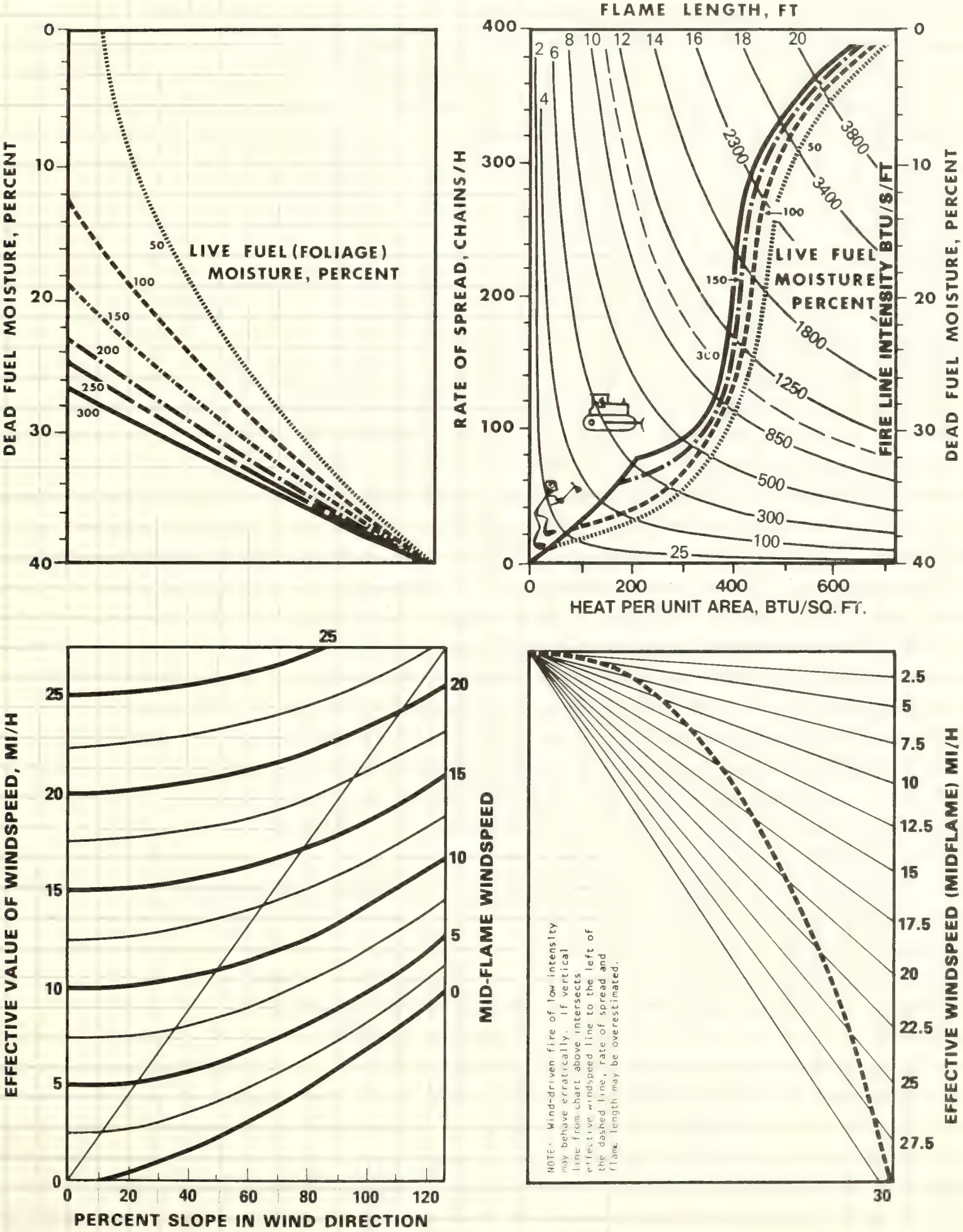
6. DORMANT BRUSH, HARDWOOD SLASH–HIGH WINDSPEEDS



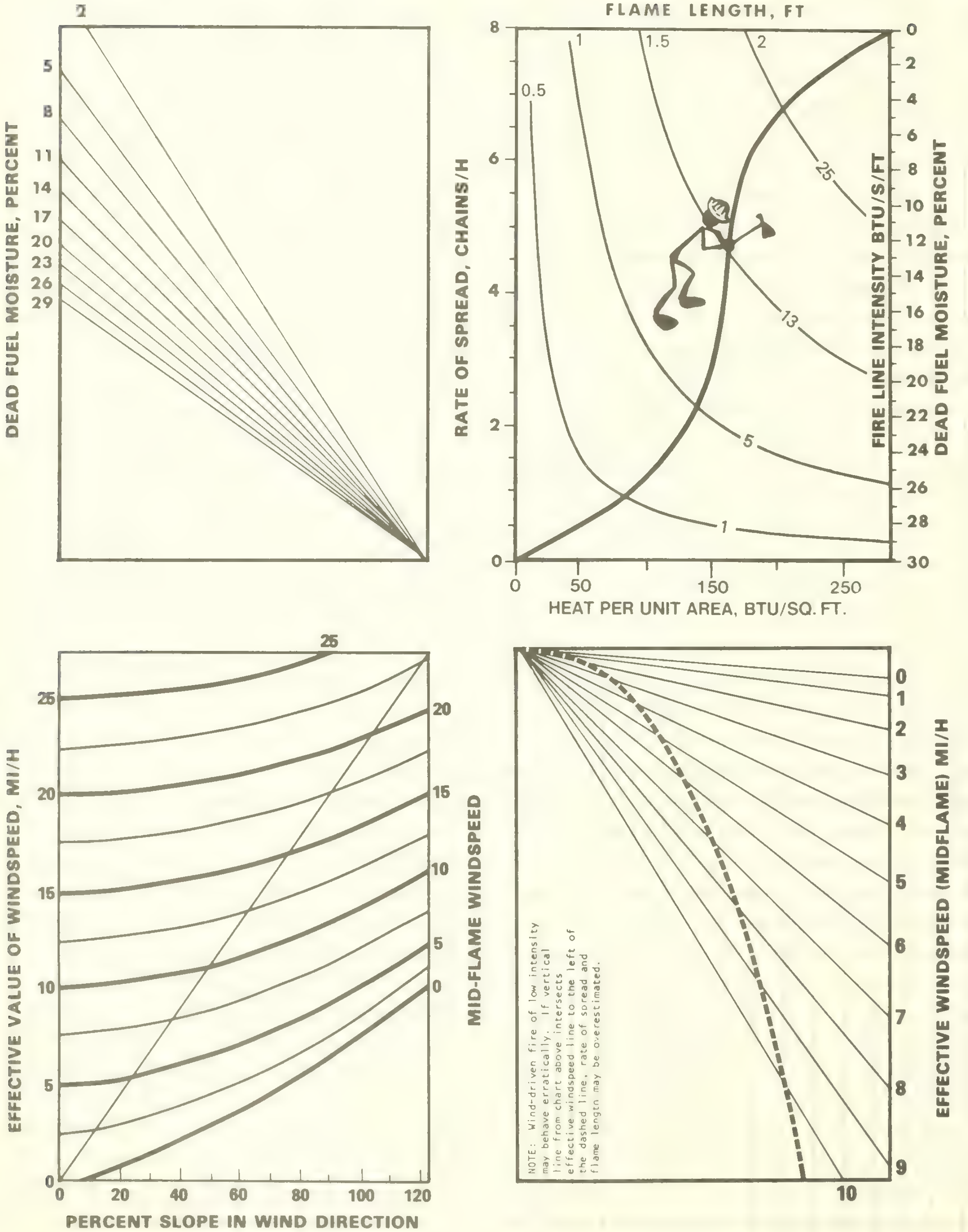
7. SOUTHERN ROUGH - LOW WINDSPEEDS



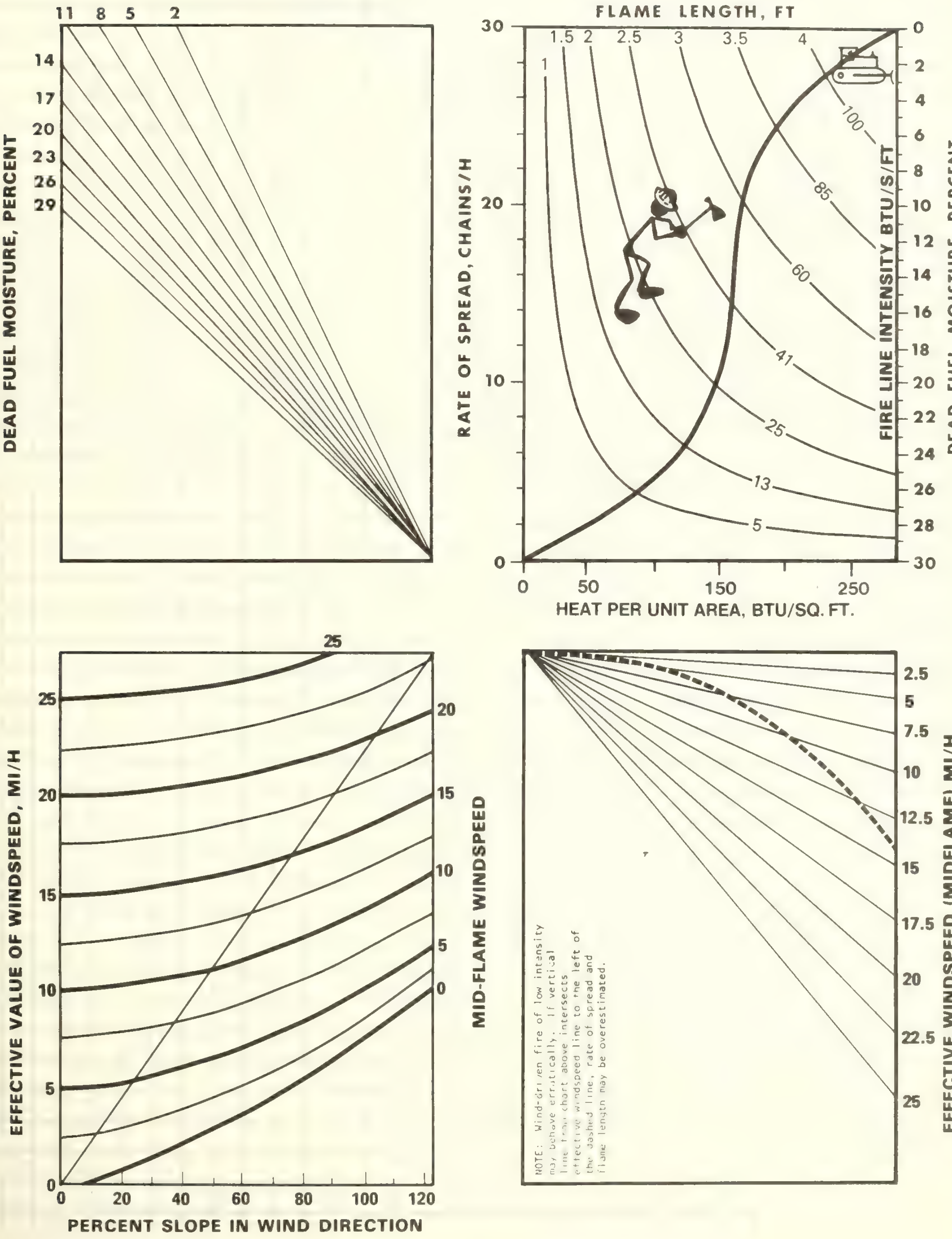
7. SOUTHERN ROUGH –HIGH WINDSPEEDS



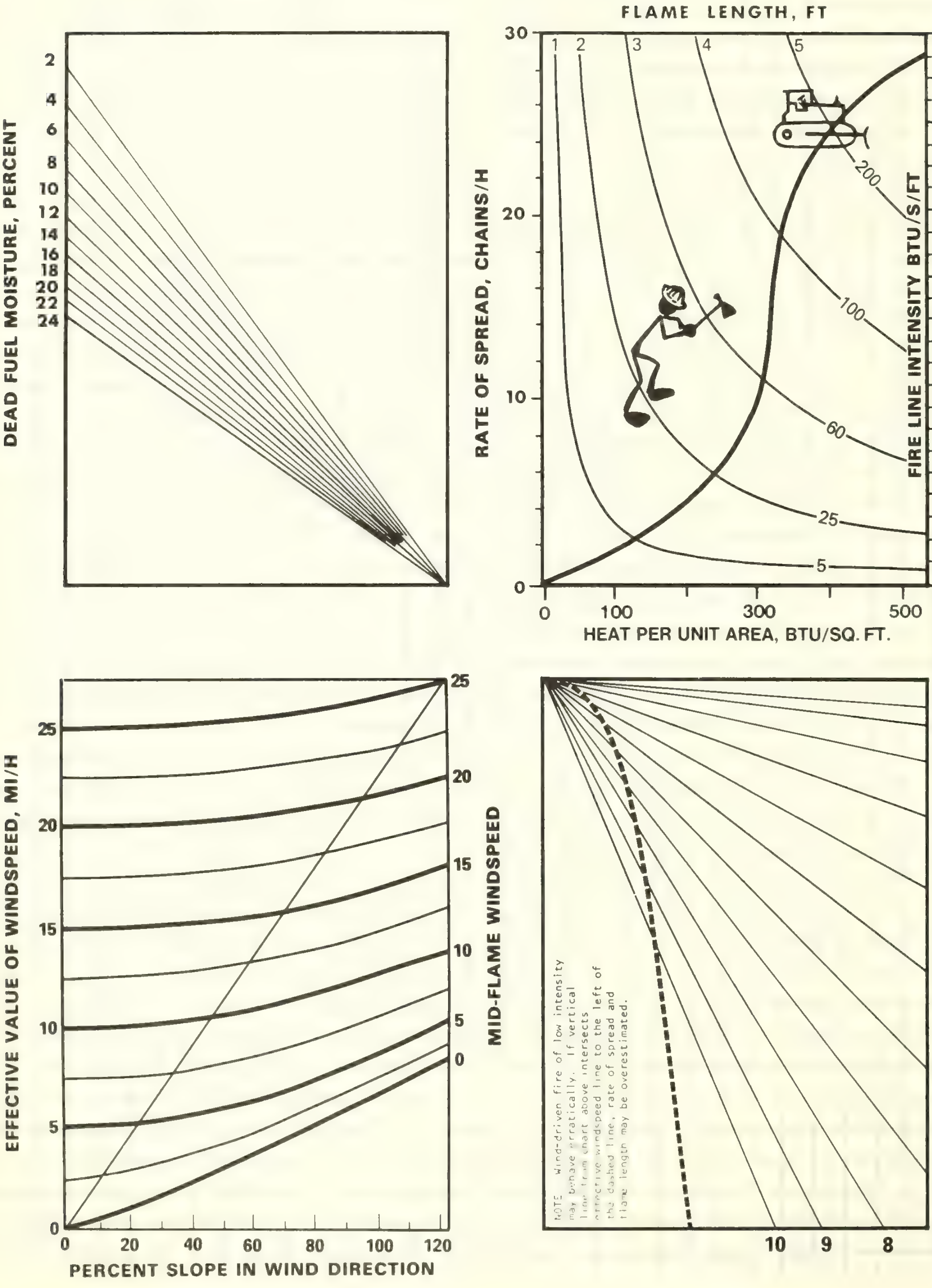
8. CLOSED TIMBER LITTER–LOW WINDSPEEDS



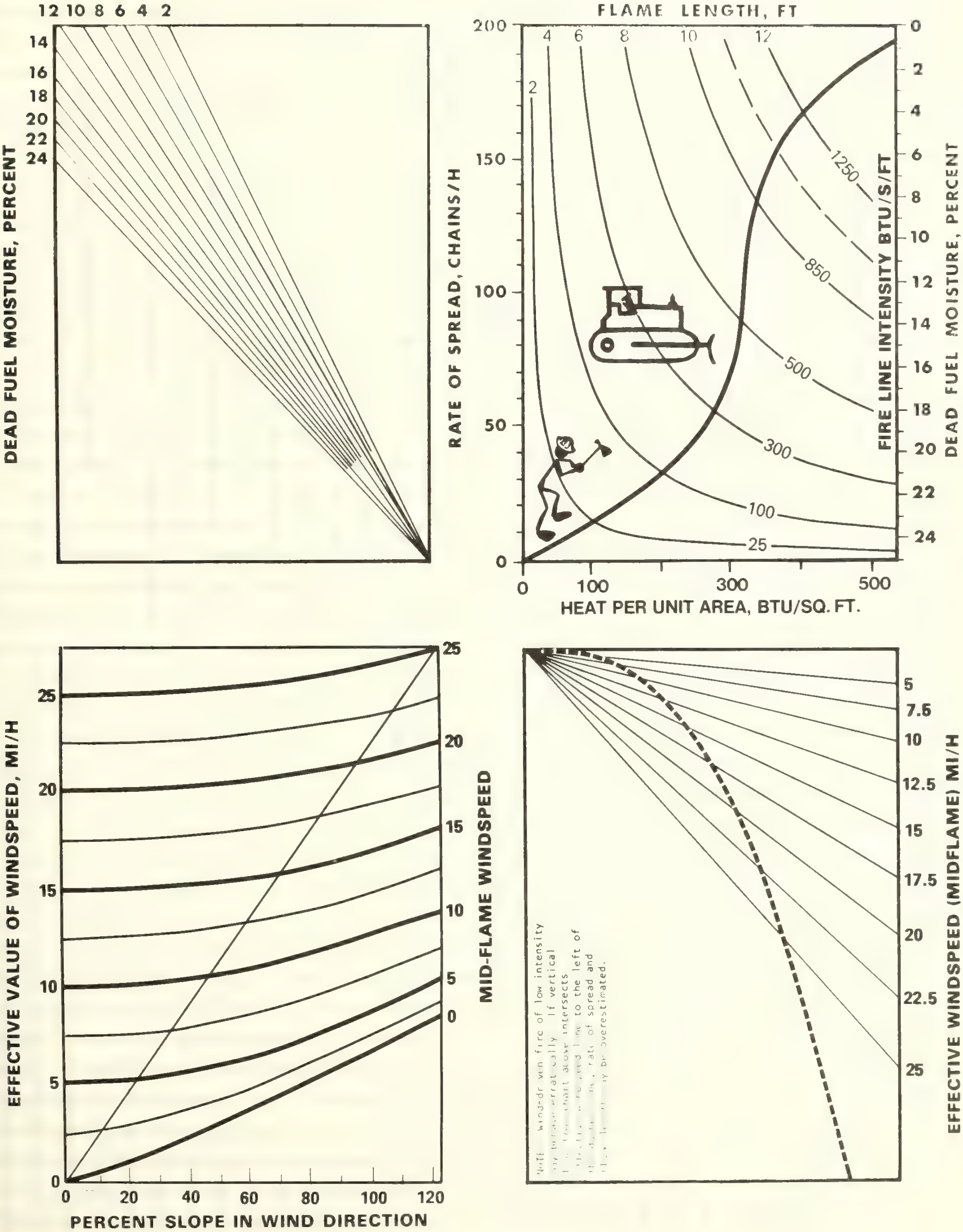
8. CLOSED TIMBER LITTER– HIGH WINDSPEEDS



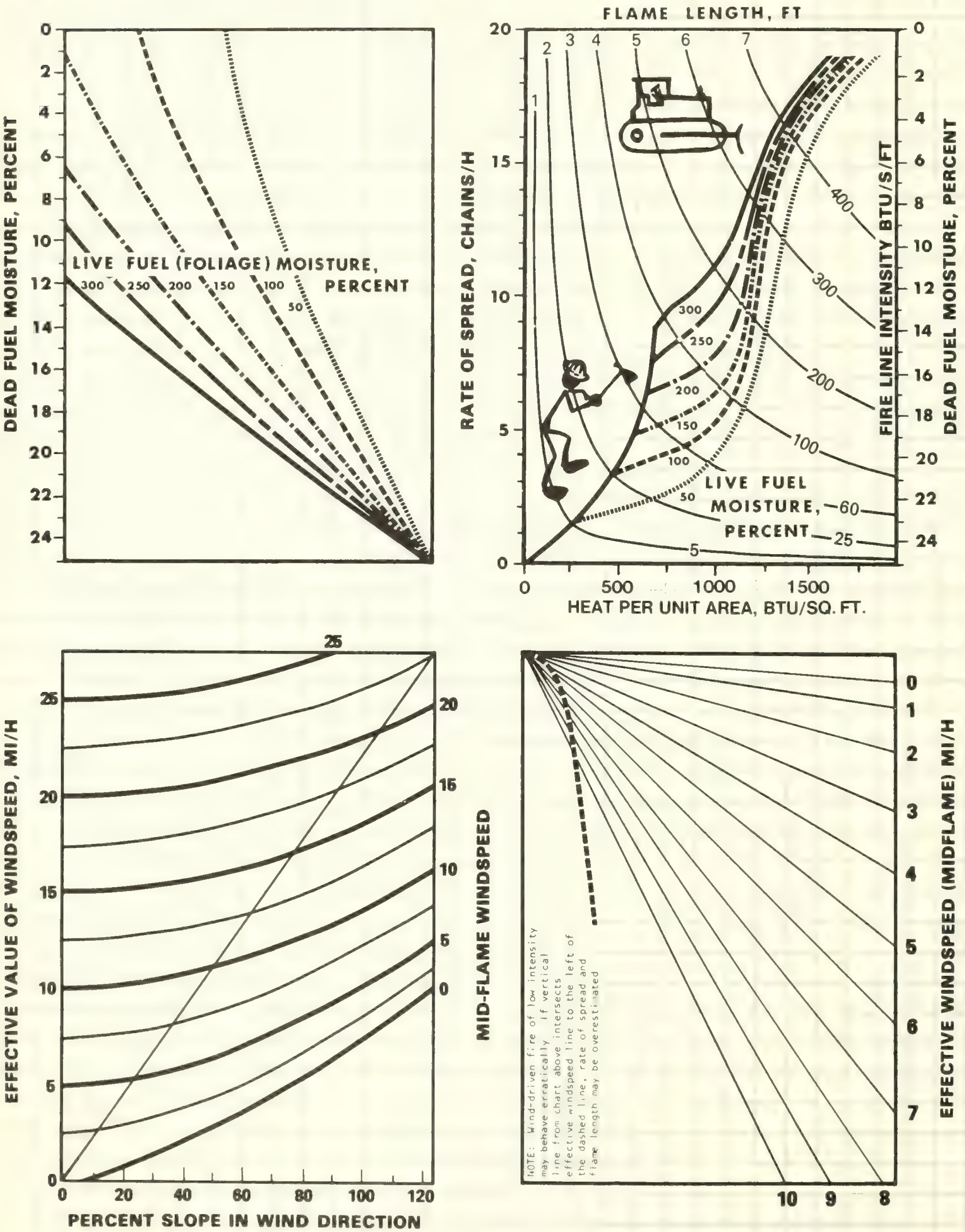
9. HARDWOOD LITTER – LOW WINDSPEEDS



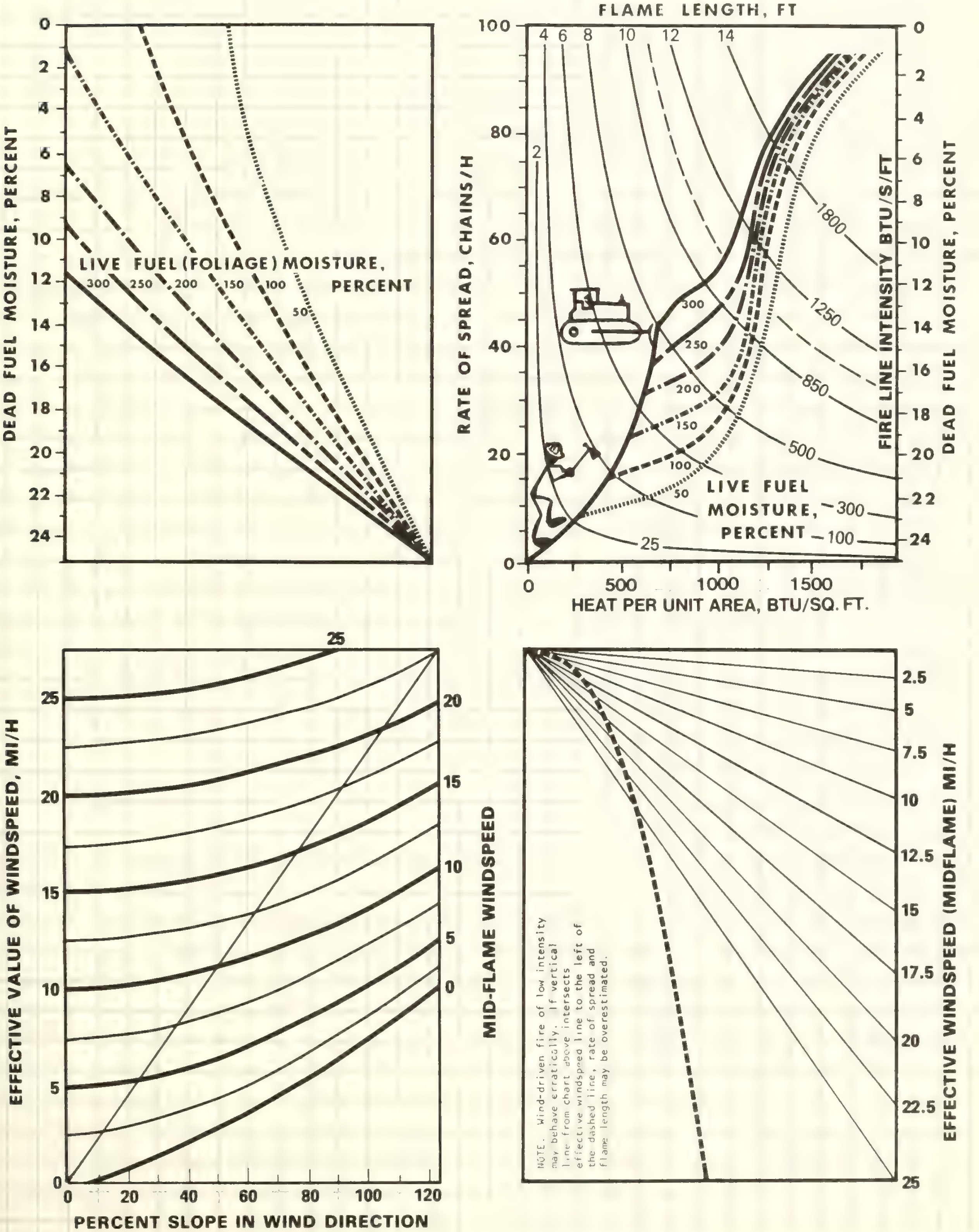
9. HARDWOOD LITTER–HIGH WINDSPEEDS



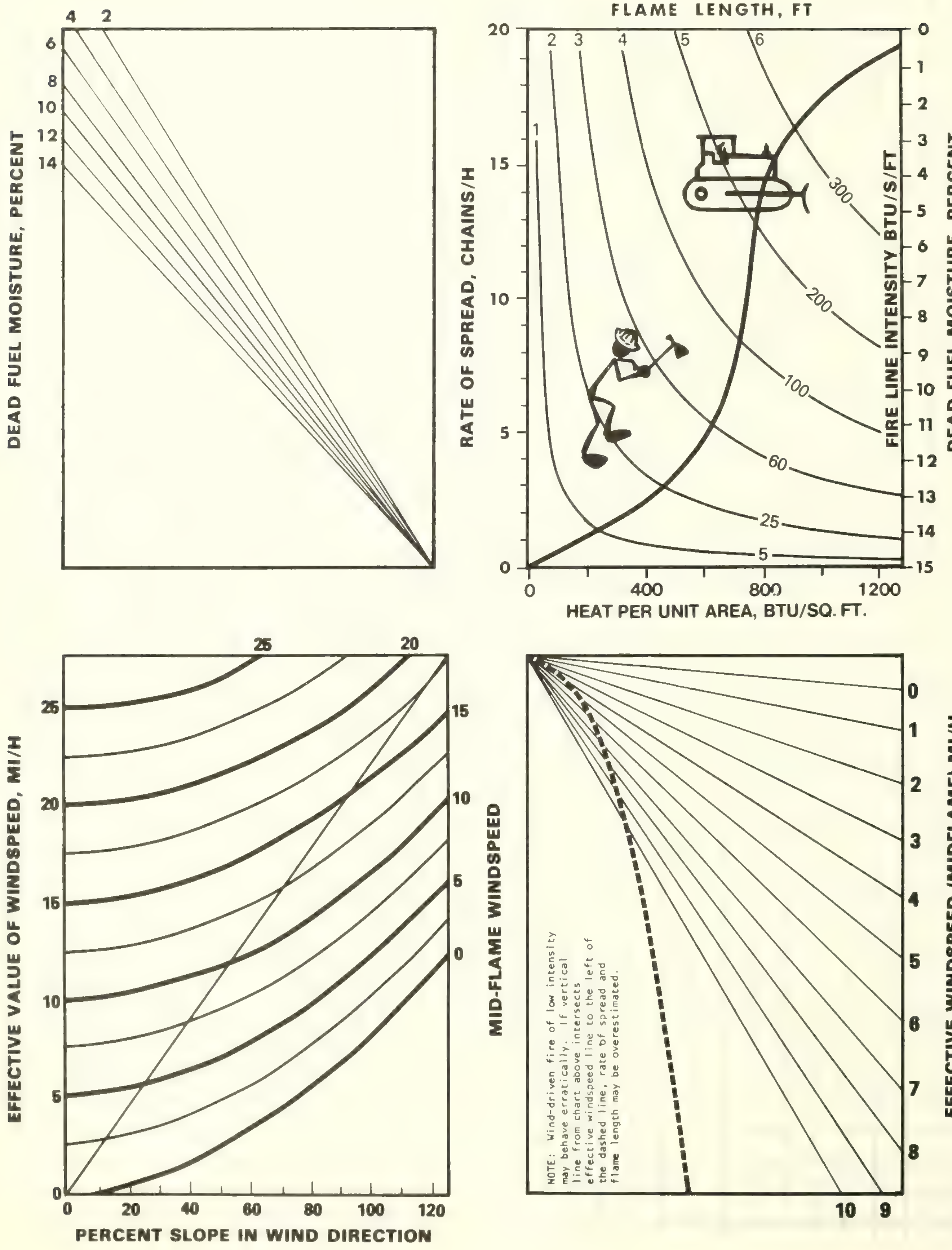
10. TIMBER (LITTER & UNDERSTORY)-LOW WINDSPEEDS



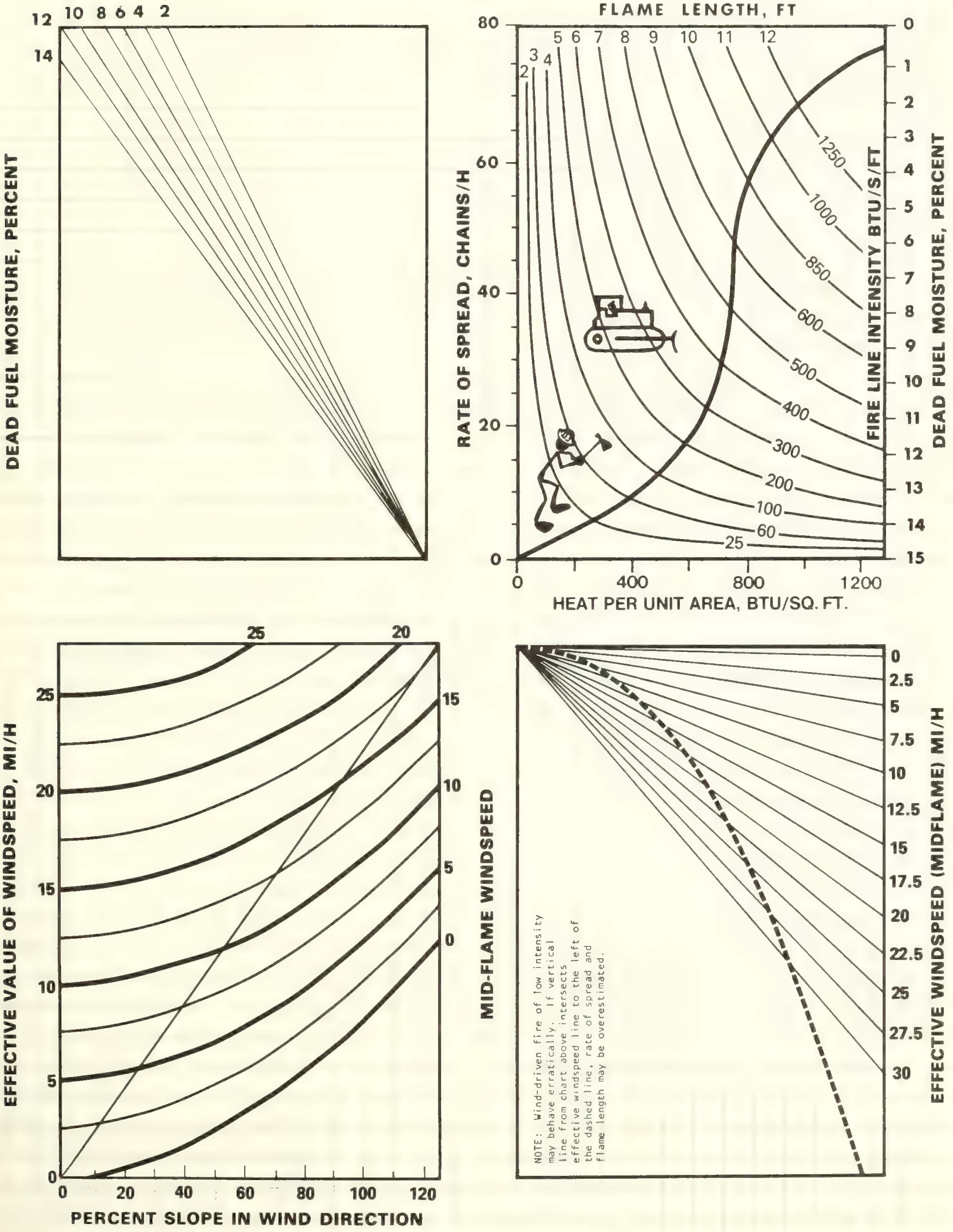
10. TIMBER (LITTER & UNDERSTORY)-HIGH WINDSPEEDS



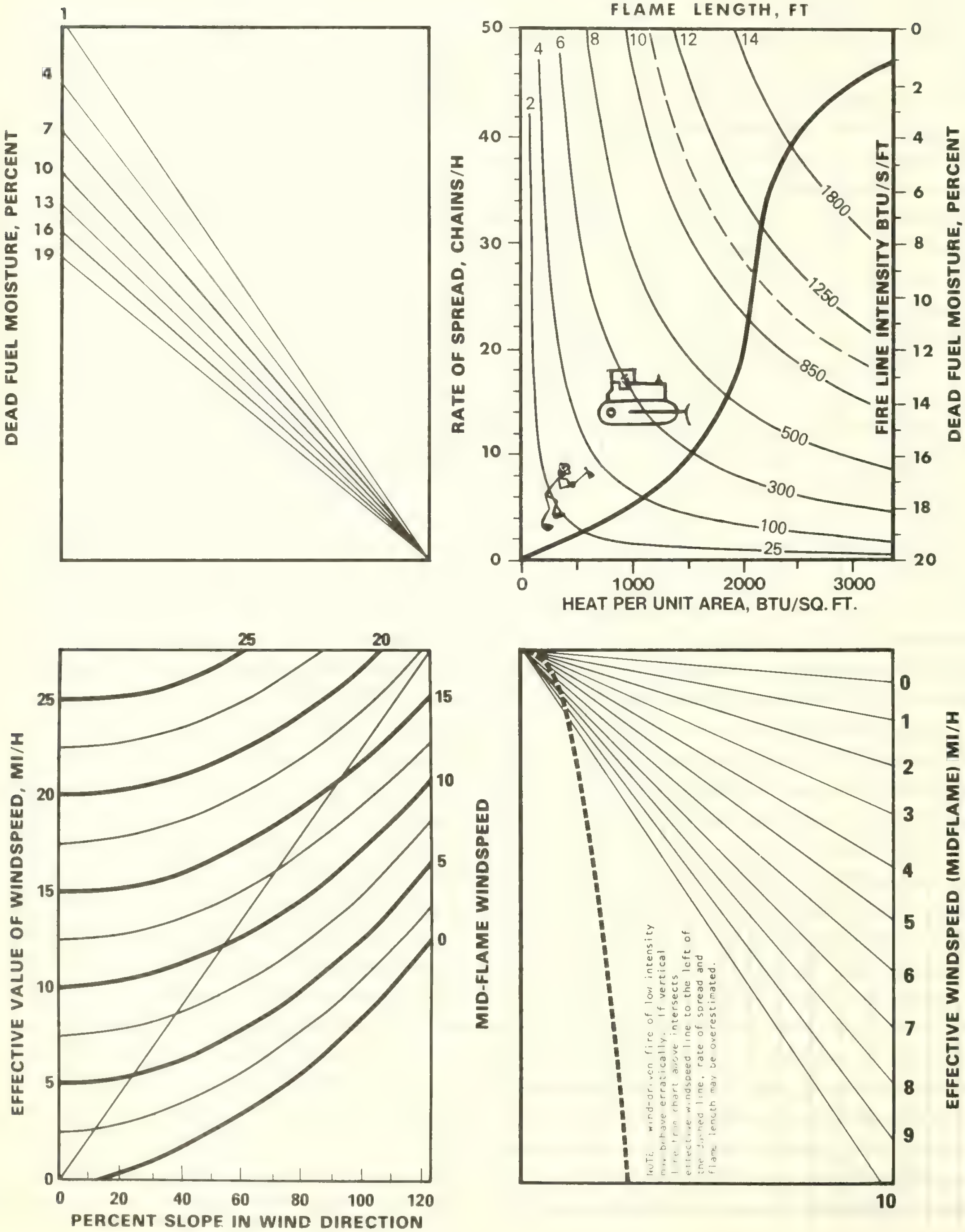
11. LIGHT LOGGING SLASH–LOW WINDSPEEDS



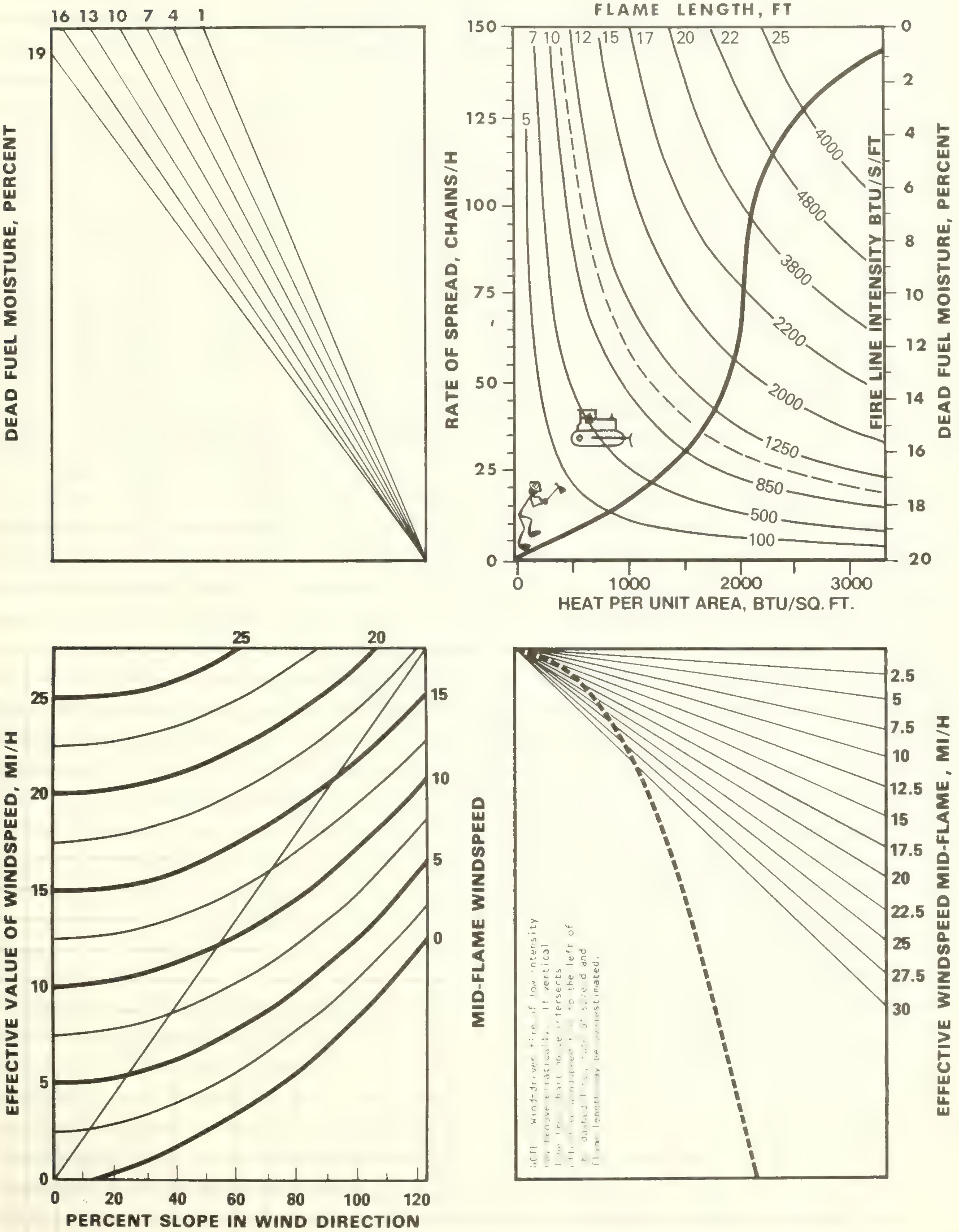
11. LIGHT LOGGING SLASH–HIGH WINDSPEEDS



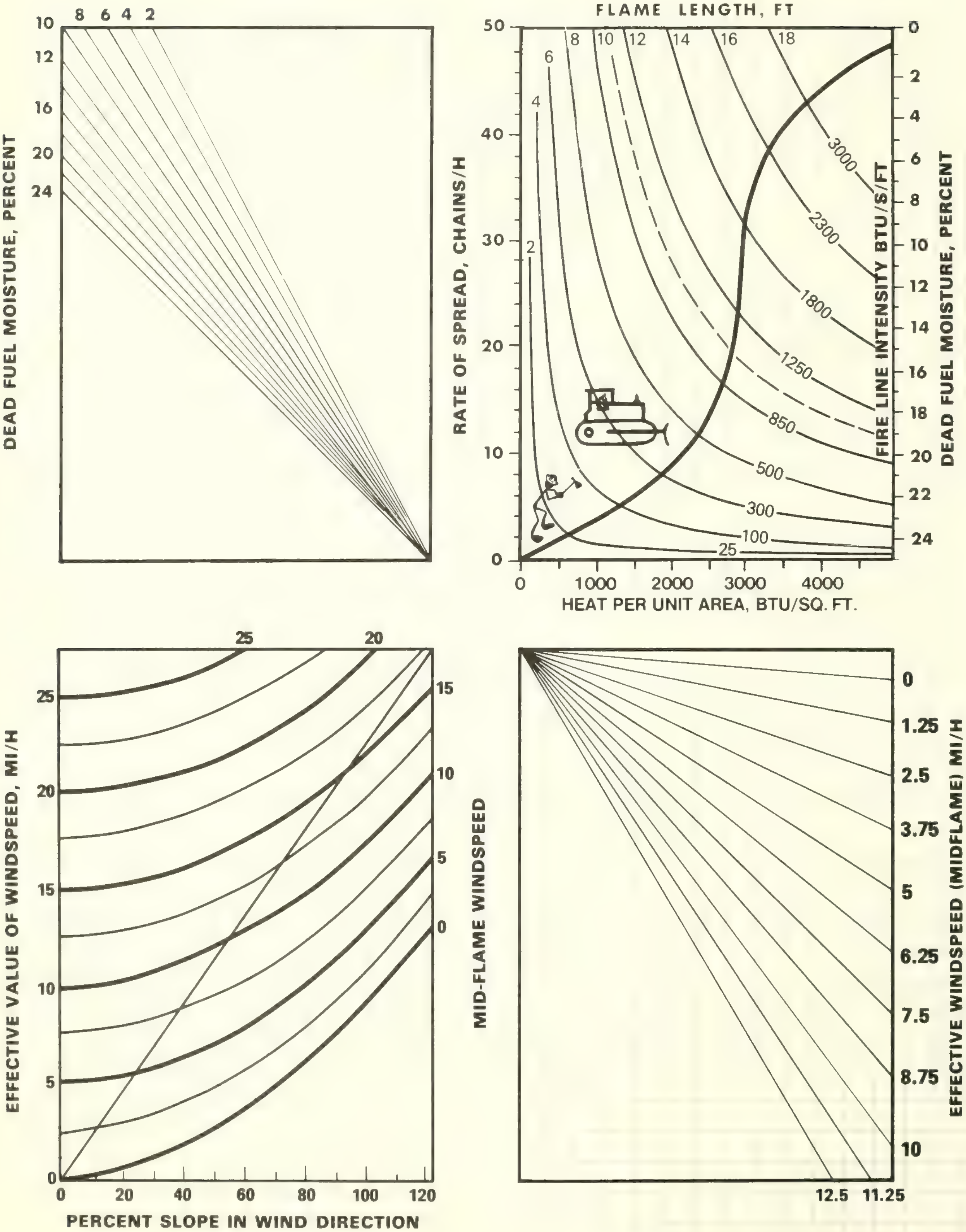
12. MEDIUM LOGGING SLASH –LOW WINDSPEEDS



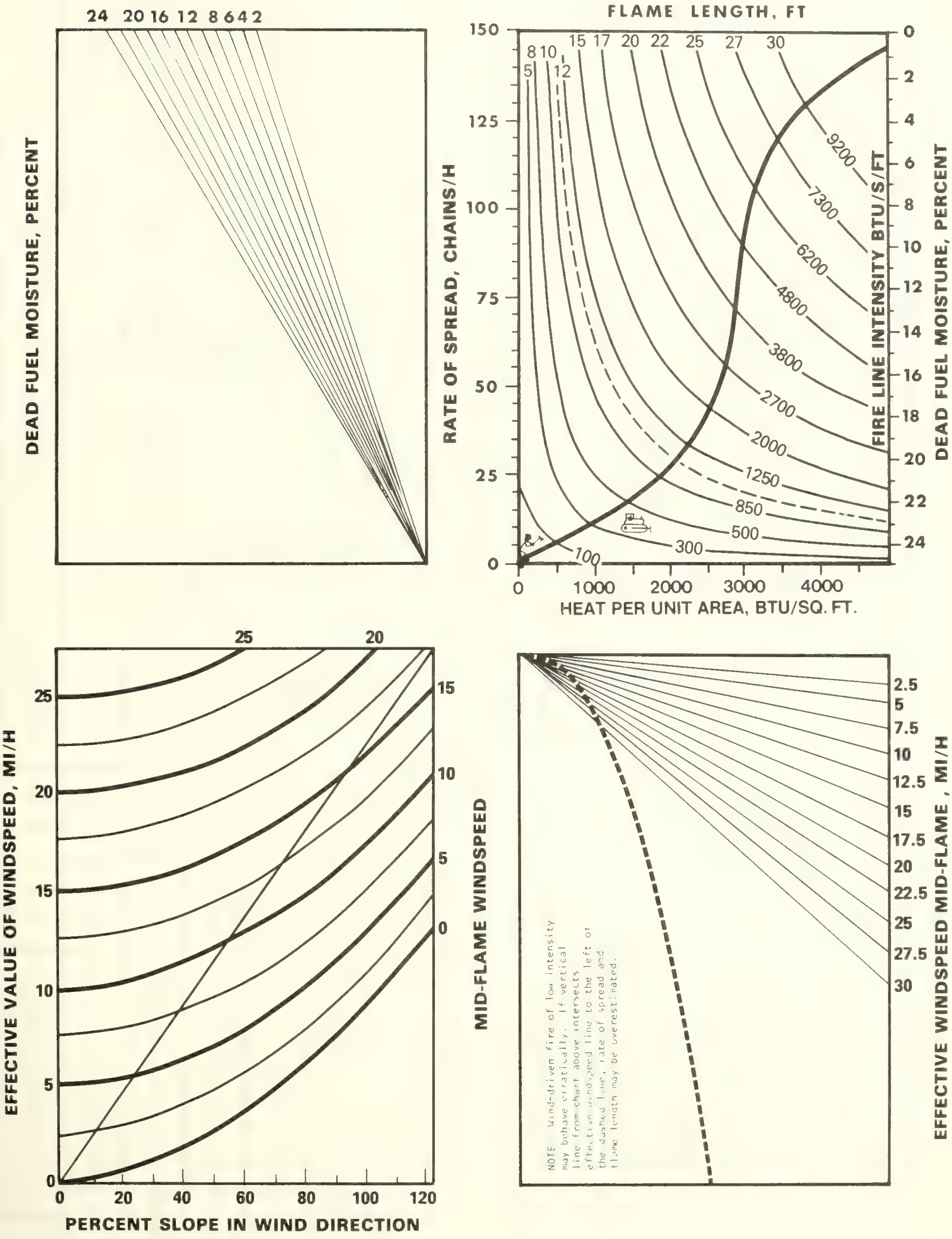
12. MEDIUM LOGGING SLASH-HIGH WINDSPEEDS



13. HEAVY LOGGING SLASH–LOW WINDSPEEDS



13. HEAVY LOGGING SLASH–HIGH WINDSPEEDS



APPENDIX B
Computation of Midflame Windspeed for the 13 Fire Behavior Fuel Models

Albini and Baughman (1979) provide the rationale for adjusting windspeed measured at 20 feet to the midflame height. Their method, and particularly their figure 2, which is reproduced here as figure B-1, was utilized to find a standard correction factor for each of the 13 fire behavior models. Without a standard, it would be necessary to calculate a midflame windspeed for every fire environment situation. It is recognized that some accuracy is lost in the process, but it is believed that this is not severe, and justified by the time saved for field work. We have found that even though flame length varies considerably with changes in windspeed, flame height is not as variable.

To use figure B-1, it is necessary to know the flame height and fuel bed depth for each fuel model. Calculation of flame height was made for dry, average, and moist conditions for each fuel model. The ratio of average midflame windspeed to 20-ft windspeed was not very different for the three conditions, so the average moisture condition, 8 percent dead, 100 percent live was used. Results are shown in table B-1.

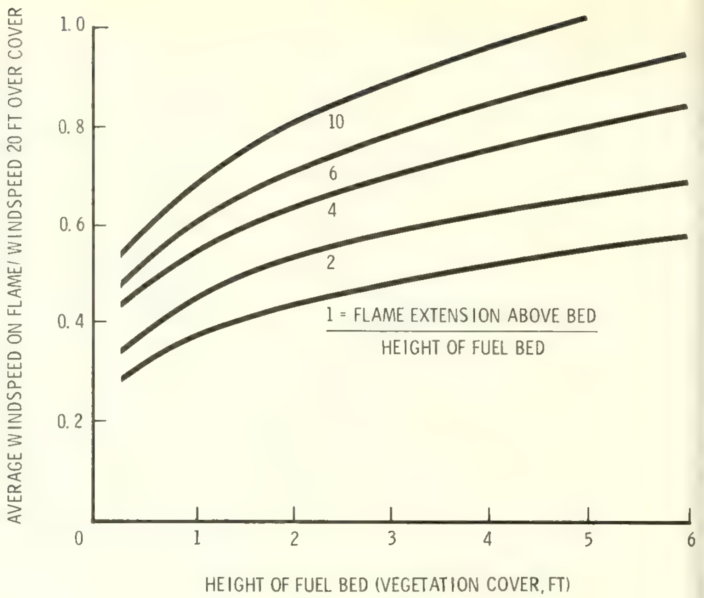


Figure B-1.—Average windspeed acting on a flame extending above a uniform surface fuelbed layer (vegetation cover), due to log windspeed variation.

Table B-1.— Data used in obtaining midflame windspeed adjustment factors for the 13 NFFL fuel models

Fuel model	Flame height[1] zero windspeed	Flame height divided by fuel depth	MWS/20′WS	Value used in wind adj table
1	0.99	0.99	0.36	0.4
2	1.6	1.6	.42	.4
3	2.7	1.1	.45	.4
4	4.9	.8	.55	.6
5	.92	.46	.35	.4
6	1.4	.56	.37	.4
7	1.4	.56	.38	.4
8	.37	1.8	.32	.4
9	.9	4.5	.44	.4
10	1.6	1.6	.41	.4
11	1.1	1.1	.37	.4
12	2.7	1.2	.45	.4
13	3.7	1.2	.48	.5

[1]Dead fuel moisture = 8 percent; living fuel moisture = 100 percent.

APPENDIX C
Calculation of Intensity Values

The three intensity values given as outputs by the TI-59 are interrelated and can be derived from each other.

I_R	= reaction intensity,	$Btu/ft^2 \cdot min$
I	= fireline intensity,	$Btu/ft \cdot s$
H_A	= heat per unit area,	Btu/ft^2
R	= rate of spread,[1]	ft/min
t	= residence time,	min

$$I = \frac{H_A R}{60}$$

$$H_A = I_R t$$

where t is dependent upon the characteristic surface-area-to-volume ratio of the fuel bed, $\tilde{\sigma}$, ft^{-1} (Rothermel 1972). Thus H_A or I_R can be calculated from the other when the residence time is known.

Anderson (1969) shows how residence time is related to fuel particle size:

$$t = 8d, \text{ min}$$

where d is the fuel particle size (inches), but

$$d = 4/\sigma$$

hence

$$t = 384/\tilde{\sigma}, \text{ min.}$$

Table C-1 gives the characteristic fuel particle sizes and residence times for the 13 NFFL fuel models.

[1]The output of both the TI-59 CROM and the nomograms is R in ch/h. To convert to ft/min, multiply by 1.1.

Table C-1.— Fuel particle sizes and residence times for 13 NFFL fuel models

Fuel model	$\tilde{\sigma}$	d	t
	Ft^{-1}	*Inches*	*Min*
1	3500	0.014	0.110
2	2784	.017	.138
3	1500	.032	.256
4	1739	.028	.221
5	1683	.029	.228
6	1564	.031	.246
7	1552	.031	.247
8	1889	.025	.203
9	2484	.019	.155
10	1764	.027	.218
11	1182	.041	.325
12	1145	.042	.335
13	1159	.041	.331

APPENDIX D
Correction 1-Hour Dead Fuel Moisture Beyond 2,000 Feet[1]

If the fire location is more than 2,000 ft in elevation above or below the location where weather conditions are known, the procedure described below can be used to calculate fine fuel moisture. It accounts for slope, aspect, and time of year as well as elevation. Caution: this procedure should be used only during the afternoon when there is good heating and no inversion.

Data needed for calculation:

Known weather site	**Projection point**
dry bulb temperature	elevation
1-hour fuel moisture	aspect
elevation	slope
aspect	amount of shade
slope	month
amount of shade	
month	

Procedure

1. Determine the 1-hour timelag fuel moisture at the known weather site using the dead fuel moisture tables in Chapt. II.
2. Use figure D-1 to determine dewpoint at the known weather site.
3. Calculate the dry bulb temperature at the projection point with the following equation. Note that when estimating temperature at a higher elevation, the difference in elevation produces a negative correction and a lower temperature. When estimating temperature at a lower elevation, the difference in elevation produces a positive correction and a warmer temperature. Adherence to the subscript notation produces the correct adjustment.

$$DB_{pp} = DB_s + \left(3.5 \times \frac{E_s - E_{pp}}{1000}\right)$$

where

DB_{pp} = dry bulb temperature at the projection point
DB_s = dry bulb temperature at the known weather site
E_s = elevation at the known weather site
E_{pp} = elevation at the projection point.

4. Calculate dewpoint at the projection point with the following equation. Adherence to the subscript notation produces the correct adjustment just as it does for temperature.

$$DP_{pp} = DP_s + \left(1.1 \times \frac{E_s - E_{pp}}{1000}\right)$$

where

DP_{pp} = dewpoint at the projection point
DP_s = dewpoint at the known weather site
E_s = elevation at the known weather site
E_{pp} = elevation at the projection point.

5. Use figure D-1 to determine 1-hour timelag fuel moisture at the projection point (uncorrected for effect of solar radiation). See example following.
6. Use table D-1 to correct for solar radiation by determining the fuel moisture correction value at the projection point. Add this correction to the uncorrected 1-hour TL FM obtained in step 4.

Enter the final value on the fire behavior worksheet, line 7.

[1]These procedures are cumbersome for field use, but are included for the serious student of fire behavior. The method was developed by Jack Cohen while working at the Northern Forest Fire Laboratory.

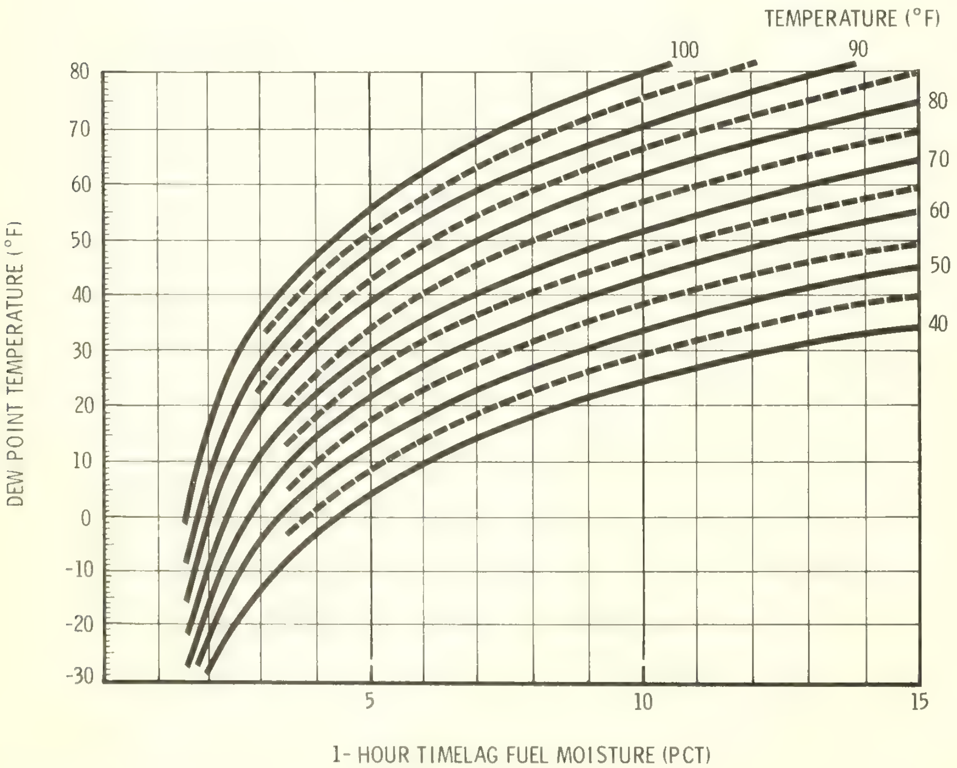


Figure D-1.—Elevation correction of l-hour timelag fuel moisture.

Table D-1.— Fuel moisture correction for aspect, slope, time of year, and canopy cover

Aspect	Slope	May June July	Feb Mar Apr Aug Sept Oct	Nov Dec Jan
		Canopy Less than 50 Percent		
N	0 – 30%	1	2	4
	31% plus	2	3	5
E	0 – 30%	1	2	4
	31% plus	3	4	5
S	0 – 30%	1	2	4
	31% plus	1	2	3
W	0 – 30%	1	2	4
	31% plus	0	1	3
		Canopy 50 Percent or More		
N		4	5	5
E		4	5	5
S		4	4	5
W		4	4	5

Example

Determine the 1-hour timelag fuel moisture on a fire given the data at the lookout tower on a warm afternoon with good atmospheric mixing.

Known weather site		**Projection point**	
1-hour TL FM	= 11%	elevation	= 3,500 ft
dry bulb temp.	= 60° F	aspect	= north
elevation	= 7,000 ft	amount of shade	= shaded
aspect	= south	slope	= 30%
slope	= 30%	month	= July
amount of shade	= exposed		
month	= July		

1. $DP_s = 44°$ F
2. $DB_{pp} = 60 + \left(3.5 \times \frac{7000-3500}{1000}\right)$

   $= 60 + (3.5 \times 3.5)$

   $= 72°$ F
3. $DP_{pp} = 44 + \left(1.1 \times \frac{7000-3500}{1000}\right)$

   $= 44 + (1.1 \times 3.5)$

   $= 48°$ F
4. Uncorrected 1-hour TL FM at projection point is 9%.
5. Correction for the projection point = 4.
6. 9 + 4 = 13 (enter on line 7 of worksheet). In this case the fuel moisture decreased 2% due to elevation correction but increased 4% due to shading.

APPENDIX E
Ignition Component[1]

Many ignitions do not survive to become detectable fires. The ignition component of the National Fire Danger Rating System (Deeming and others 1977) was developed to identify fuel and weather conditions that would cause a fire to sustain itself long enough to be detectable. As conditions promote an increasing rate of spread, the ignition component increases until every ignition survives to become a detectable fire. Ignition component (IC) is always less than or equal to the probability of ignition (P(I)). Ignition component is an output of the fire behavior program of the TI-59 equipped with an NFDR/Fire Behavior CROM. Consider ignition component to be the probability, expressed as a percentage, that a firebrand will cause a detectable fire. To obtain maximum confidence, ignition component should be calibrated to the fuels and conditions of an area. Although IC does not include a factor to account for the number of ignition sources (firebrands), it generally relates to fire occurrence. A cross plot between number of detected fires and ignition component for a particular fuel model will provide the calibration. This should be done with historical data. Ignition component is more suited for planning purposes. It is recommended that probability of ignition be used during operations on wildfires and prescribed fires where the production of firebrands is probable and ignitions may hold over for a period of time before conditions change and cause them to become detectable fires.

[1]Explanation of ignition component from lesson plan material developed by Pat Andrews.

APPENDIX F
Fire Intensity Required to Cause Crown Combustion

Martin E. Alexander developed the enclosed graph (fig. F-1), which identifies the surface fireline intensity necessary to cause tree crown combustion based upon the height to the live crown base and the foliar moisture content of the tree crowns. This is as yet unpublished. Foliar moisture content of conifers is obtainable from the literature.

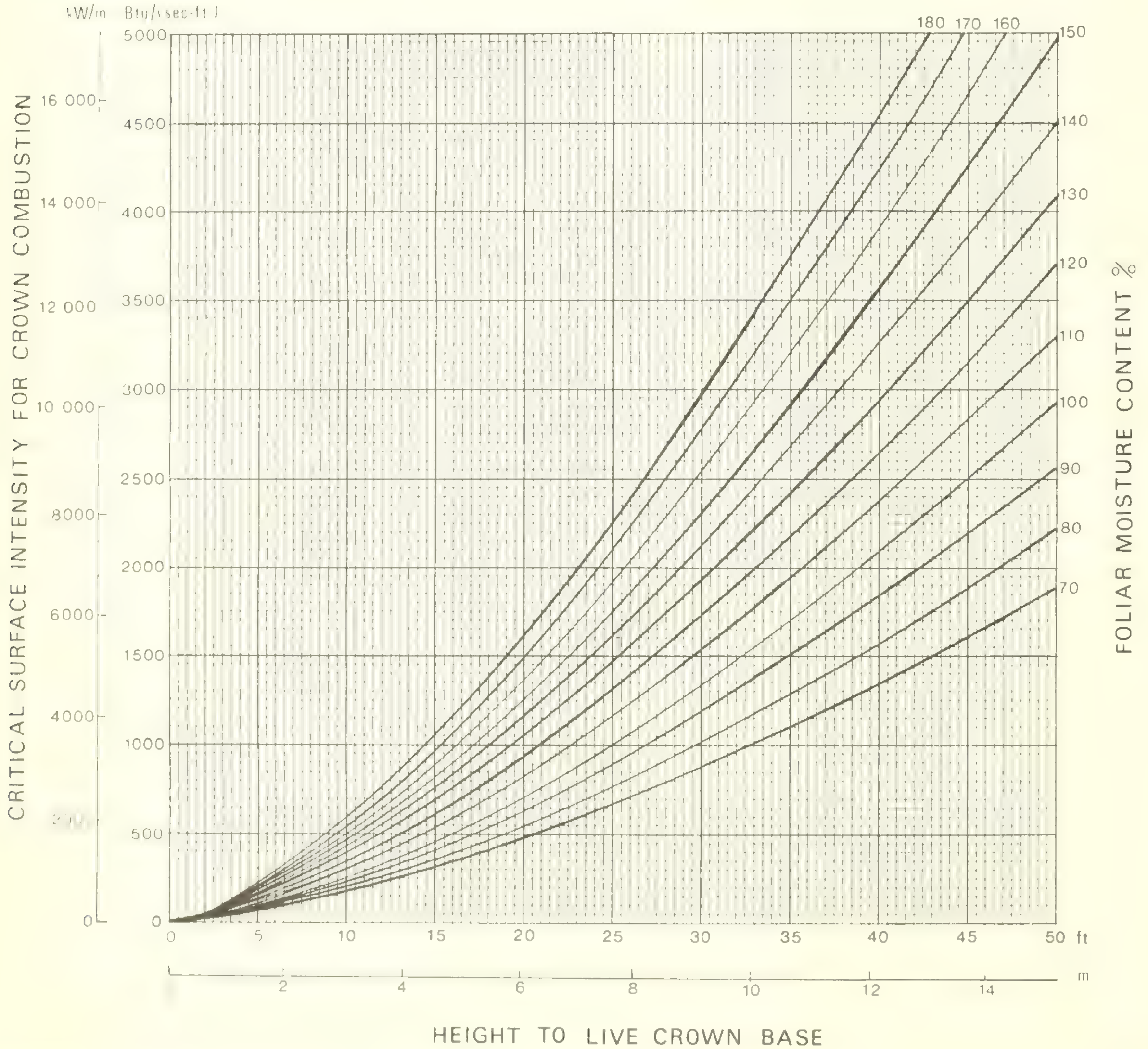


Figure F-1.—Surface intensity required for crown combustion.

APPENDIX G
Fire Example - Blackfoot Fire

This example is based on the Cabin Fire which burned in the Scapegoat Wilderness Area in northwestern Montana in August 1979. It has been adapted from a simulated fire exercise taught during FBO training by Ron Prichard. (Ron is an FBO on a Class I team in Region 1.) The purpose of this example is to illustrate how an FBO operates in a fire situation, and how the predictions are used by the fire staff. Examples of briefings and fire behavior forecasts are given along with strategy briefings prepared by other fire staff officers.

Blackfoot Fire - Exercises
EXERCISE 1
Mobilization, August 5, 1979

Situation
You have been called to the Missoula Aerial Fire Depot, arriving at 2100 hours on Saturday, August 4, 1979, to await the arrival of the remainder of the fire overhead team to which you are assigned. All members are expected to arrive in Missoula by 2330 hours, then transportation has been arranged to bus your team to a staging area near the fire. Missoula Aerial Fire Depot is headquarters of the regional fire coordinator and a smokejumper base. Missoula also is headquarters for the Lolo National Forest, on which this fire is burning. The National Weather Service office is located at the Missoula airport, and fire weather meteorologists are available at this facility. You are able to learn the location of the fire (approximately 60 air miles northwest of Missoula) and that it started earlier today from an abandoned campfire. The fire is burning in the Scapegoat Wilderness Area, and the nearest road is approximately 10 miles by trail. Eight smokejumpers were dispatched to the fire after discovery, but were unable to jump because of strong winds in the area. They reported that the fire was burning very hot in mature timber and ground fuels. It appeared to be 125 to 150 acres in size at 1600 hours when the jumpers departed the fire area. A 20-person district crew was dispatched to the fire at 1545 hours, but no word has been received of their arrival or effectiveness on the fire.

Assignment
You are an FBO with the overhead team assigned to this fire.

1. What will you do, if anything, while waiting arrival of your team members in Missoula? In brief outline form, write the actions you would take to prepare for your assignment.

Solution Example

1. Locate fire from best information available, using whatever map can be found. If possible determine forest, district, legal description, physical features, elevation, etc.
2. Try to determine location and manning status of lookouts in the area. (May be able to contact lookouts by radio.)
3. Call Weather Service for local general weather conditions and forecasts. Talk with person on duty. Identify yourself, explain your need for information, pass along fire location and elevation (as accurately as possible), and let him know you will be requesting spot weather forecasts for the fire area. Ask what time daily general fire weather forecasts are available.
4. If possible, secure a topographic map of the area and mark fire's location using best intelligence available. Slopes may be calculated for terrain around the fire's location.
5. Discuss local wind and weather patterns with people familiar with that area. Determine if local fire management officer or other knowledgeable person is available to interview regarding the area. Learn as much as possible about the fuels.
6. Determine availability of mobile or portable fire weather station and meteorologist. Ask for assignment to your fire if you can determine need without first visiting fire.
7. Take the opportunity to charge the batteries in your TI-59 calculator and any other calculator you normally use.
8. If you have access to accurate map or photo plot of fire, and are able to determine how long fire has been active, you may determine rate of spread exhibited by the fire and perhaps direction of run.
9. Try to secure a copy of the NFDRS form D9b from the weather station closest to, or most representative of, the fire.

EXERCISE 2
First day on fire, August 5, 1979

Situation
It is now 0930 on August 5, 1979, and you and your complete fire team have arrived in fire camp and are scheduled to receive a briefing from the initial attack fire boss in about 10 minutes. In addition, the fire weather meteorologist who has been assigned to the fire arrived about an hour ago and will brief you on the weather. Your team is assuming command of the fire at 1030 hours today (1 hour from now) and the plans chief has asked you to determine what the fire is likely to do the remainder of today, until 2000 hours when winds and heating should subside. There is a strategy session scheduled for 1400 hours today that you will be expected to attend and for which you will be expected to provide fire behavior information.

Assignment
After attending the initial briefing:

1. Prepare a brief but complete outline of your actions necessary to provide the needed fire behavior information for today's fire growth and the 1400 hour strategy session.
2. Make a projection of fire growth for the remainder of today (from 1000 hours until 2000 hours). Map the expected fire perimeter. Use the manual (nomogram) process for projecting fire growth. Remember that time is short and work with only those projection points you actually need!

BLACKFOOT FIRE
EXERCISE 2
Briefing Material

1. Fire Statistics
   a. Name of fire Blackfoot Fire
   b. Approximate size of fire 400 ac. @ 0600 8/5/79
      Location of fire E. Fork Blackfoot River T23N R10W S34 (provide map)
   c. Time of fire start Est. 1400 hours 8/4/79
   d. General weather Hot, dry; highs mid 80's - R.H. lows 15%; winds WSW with upslope to 15-18 mi/h, erratic at times. Temperature inversion in valleys below 6,000 ft until 1000 hours each day.
   e. Fuels at fire Mature conifer w/brush and ladder fuels on east flank
      ahead of fire same; fuel moisture from Lincoln D9b
      (1400 8/4/79) 10 hr TL = 10% 100 hr TL = 14%
   f. Fire behavior and spread Rapid downwind spread w/crowning and spotting up to 1/4 mile. Fire has burned into brush and ladder fuels on the east flank.
   g. Weather forecast Continued hot and dry with westerly winds to 15 mi/h daily. Temperature inversion below 6000 ft until 1000 hours.
   h. Is it a tanker show? Ground No Air Yes
   i. Is it a helicopter show? Yes
   j. Anchor points West flank at river near point of origin.
   k. Line held Approx. 20 chains constructed and held.
   l. Natural barriers None present to stop fire.
   m. Camp location 1/2 mi NW of origin in Sec. 28 (see map) elev. 5660 ft.
   n. Other fires on forest 2 lightning starts on 8/4—both contained.
   o. Present priority of this fire No. 1 on Forest, high Regional priority
2. Delegations and Assignments
   a. Initial attack fire boss Smokey Burns
   b. Forest Supervisor Rep. Sam Brown
   c. District Ranger Rep. Larry Fellows
   d. Resource advisor(s) Sharon Biggs
3. Local Fire Policy Standard policy, minimum use of mechanical equipment due to Wilderness. Least cost control appropriate with resource values at risk.
4. Resource and Development Values Main line trail up valley is heavily used by stock and hikers. Six native timber bridges on trail in vicinity of fire with estimated replacement value of $120,000.00
5. Control Objectives Prevent spread north into main Blackfoot River drainage. Limit eastward spread to avoid burning valuable wildlife habitat in the upper East Fork drainage.
6. Legal Considerations Private land SW of fire in Sec. 5 (approx. 1 mile) Investigation presently underway into cause of fire.
7. Pre-attack plans? Yes No X
8. Local Hazards Occasional grizzly bear, moose with calves, some steep terrain with rolling rocks.
9. Local Political Considerations Classified wilderness area. Minimum of mechanized equipment use and site alteration. Area is frequented by many national conservation/preservation groups.
10. Other agencies assigned None at present. National Guard requested for air support. (cargo drops)
11. Manpower on Fire 20 person District crew. 14 organized crews ordered, ETA 1400 hours 8/5/79
12. Equipment on Fire 1 - 206 helicopter, handtools. (2 short strings mules ordered, ETA 1400 hours 8/5/79)
13. Land Status All National Forest lands
14. Rehabilitation Policies Waterbar all control lines, seed disturbed areas with mixture provided by District, lop and scatter limbs and other slash created outside firelines.
15. Communications Fire net (Tach 2). Forest radio for outside communications. (ch1 direct - ch2 repeater)
16. Other:

At time of discovery, winds of 40 mi/h were estimated on the fire, caused by passage of weak low pressure system. Winds began to subside near 1800 hours last night and have returned to normal daily patterns common for this time of year. During initial run of fire, crowns were consumed in some areas, spotting was observed for an estimated 1/2 mile, and rates of spread were estimated at near 40 chains per hour through the mature timber stands. Fire remained on the ground and has traveled at much slower rate during the hours of darkness last night. Islands of unburned fuel remain in the area where fire missed or didn't enter the crowns as ground fuels were consumed.

Morrell Lookout, located 24 miles west of the fire at 7,700 feet, has been providing weather observations during the day on a 2-hour schedule. He can be reached by Forest net radio.

Summary of Fuel Conditions

In the old burn (see fuels map), 75 percent of the area is covered with brush approximately 2 ft in height, with very little dead material present. Foliage is not highly flammable. Twenty-five percent of the area is covered by short needle conifer reproduction thickets up to 25 ft in height, with branches near to the ground. These closed areas of reproduction have shaded out the brush from the understory, leaving a needle layer and a sparse herbaceous component which is carrying the fire. Thickets vary in size from a few feet across to a quarter of an acre, with occasional single trees surrounded by brush. Occasionally, fire will enter crowns of conifer reproduction, causing torching and spotting. A few veteran Douglas-fir trees that survived the earlier fire are scattered throughout the area.

In the grassy parks on the ridges and upper slopes (see fuels map), cover is short grass up to 18 inches in height growing under a sparse tree cover. Grass fuels are less than 30 percent shaded by the overstory trees. Some litter and short brush is present in areas, but is not heavy.

The remainder of the area is covered by a mixed stand of conifers that are mature to overmature. Species include DF, L, LPP, and AF, S at higher elevations. Medium to heavy loadings of dead and down fuels are present under the overstory trees. The dominant trees (DF and L) are generally 90 to 120 ft tall and up to 24 inches in diameter.

Summary of Weather Observations from Morrell Lookout

Date	Time	D.B. temp. (°F)	R.H. (%)	Winds (mi/h)
Aug. 4, 1979	1400	81	19	SW @ 30 with gusts to 45
	1600	81	18	SW @ 35 with gusts to near 50
	1800	79	22	SW @ 22 with occasional stronger gusts
	2200	72	26	WSW @ 8
Aug. 5, 1979	0600	46	44	Calm

WEATHER FORECAST

NOAA WEATHER SERVICE — FORECAST #1
Missoula Portable Weather Unit — Blackfoot Fire Camp
Forecaster: Dave Goens — 0930 m.s.t. 8/5/79

DISCUSSION:

Weak pressure field over the Pacific Northwest. Weather pattern is very stable with no important changes foreseen. Temperature inversions will occur in valleys below 6,000 ft until 1000 hours daily.

DAY SHIFT, Monday, Aug. 5

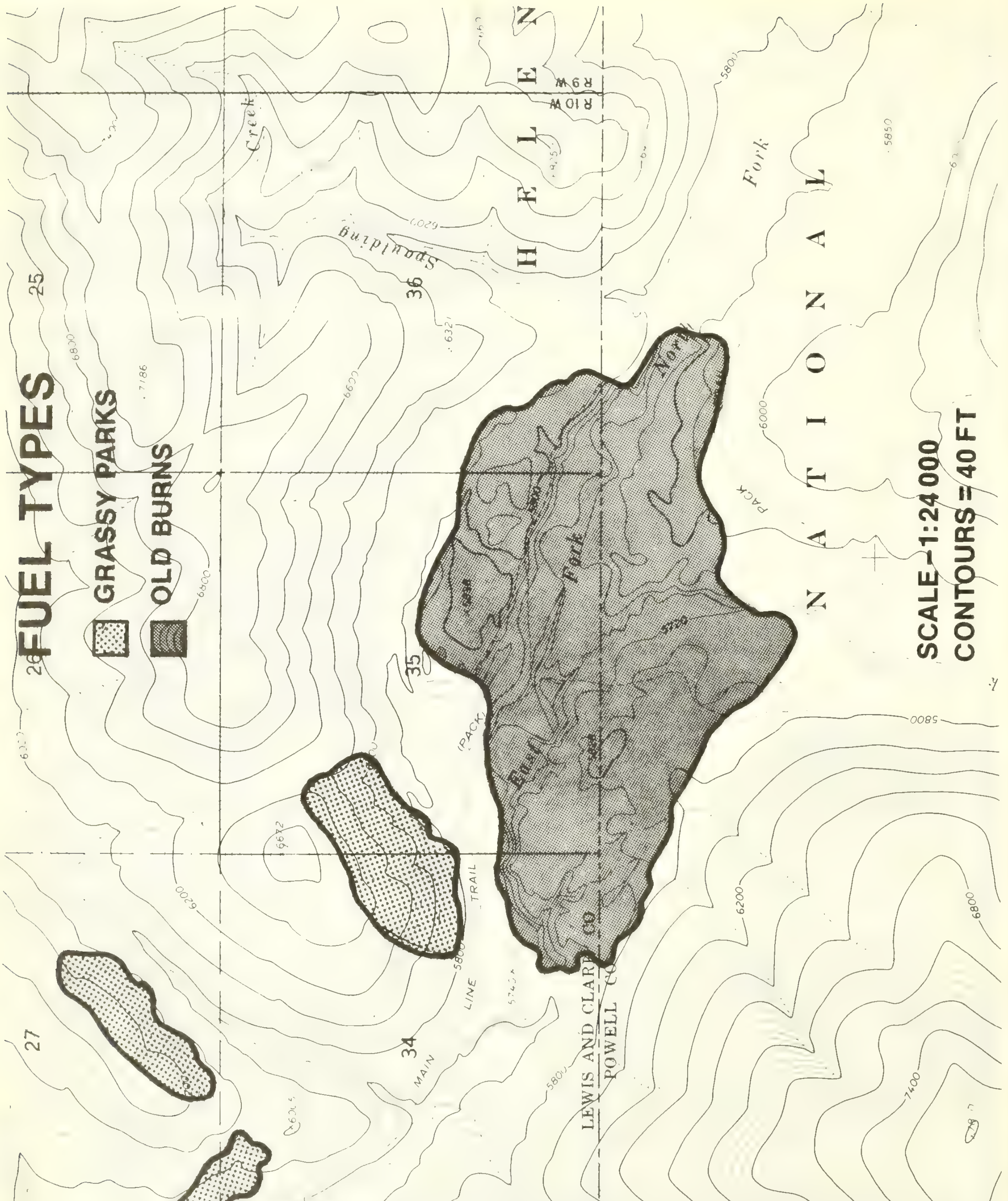
Little change today. High temperature 88° F at fire camp and along the lower slopes, 80° F near the ridgeline, minimum humidity 15 percent lower slopes, 20 percent upper slopes. Winds SW with up-canyon/upslope 5 to 10 mi/h by 1100, increasing to 10 to 15 mi/h and gusty by midafternoon.

OUTLOOK:

Tuesday and Wednesday - Little change from very warm and dry.

NIGHT SHIFT, Monday, Aug. 5

Up-canyon/upslope winds decreasing after 1930. Winds light downslope/down-canyon by 2100. Temperatures cooling into upper 30's at fire camp by sunrise and into mid to upper 40's on the mid and upper slopes. Humidity recovery to 70 percent in drainage bottom and to 45 percent on mid to upper slopes.


FUEL TYPES
GRASSY PARKS
OLD BURNS
SCALE—1:24 000
CONTOURS = 40 FT
HELENA NATIONAL
LEWIS AND CLARK CO
POWELL CO
MAIN LINE TRAIL
(PACK)
East Fork
North Fork
Spaulding Creek
R10W R9W

Solution Examples

Assignment 1. Action outline.

1. Try to get aerial reconnaissance of fire, fuels, and terrain in advance of the fire front. Ground reconnaissance of potential trouble spots would be extremely helpful if time permits.
2. Gather as much intelligence as possible from line personnel who have been on the fire (previous winds, fuels, temperatures, behavior, spotting, etc.).
3. Get belt weather kits into hands of line scouts, intelligence officers, or others who can provide observations from the line. (Be sure they know how to use the kit.)
4. Determine need and location of weather watchers and make operational.
5. Put together best possible fire status map from which to make projections.
6. Investigate availability and desirability of infrared mapping flight.
7. Determine location of various fuel types and slopes ahead of fire and select projection points.
8. Determine input variables (values) for projection to be made from 1000 hours to 2000 hours.
9. Prepare briefing for overhead strategy meeting using information developed by use of intelligence at hand.
10. Convert fire behavior terminology into terms that are easily understood by overhead team.
11. Check one more time with meteorologist for any late weather changes just prior to making projections.
12. Make any adjustments in projections, predictions, or briefing made necessary by late changes or added intelligence.
13. Check with the safety officer and the resource coordinator to determine if any special conditions must be stressed in your forecast or briefings.

FINE DEAD FUEL MOISTURE CALCULATIONS

		FM-8	FM-5	
a. Projection point	1	2	2	3
b. Day or night (D/N)	D/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	84	85	88	82
d. Relative humidity, %	17	17	15	20
e. Reference fuel moisture, % (from table A)	2	2	2	3
f. Month	Aug	Aug	Aug	Aug
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time	1400	1400	1400	1400
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect	S	-	-	N
k. Slope	31	0	0	31
l. Fuel moisture correction, % (from table B, C, or D)	4	4	1	4
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	6	6	3	7
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E) Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 2

NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79 TIME 0930

PROJ. PERIOD DATE 8/5/79 PROJ. TIME FROM 1000 to 2000

Two-fuel-model concept

INPUT DATA

No.	Item		Label					TI-59 Reg. No.
1	Projection point			1	2	2		
2	Fuel model proportion, %			100	25	75		
3	Fuel model			10	8	5	8&5	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	2	2	0		60
5	Dry bulb temperature, °F		DB	84	85	88		61
6	Relative humidity, %		RH	17	17	15		62
7	1 H TL FM, %	Nomogram use	1H	6	6	3		28
8	10 H TL FM, %		10H					63
9	100 H TL FM, %		100H					30
10	Live fuel moisture, %		LIVE	100	-	100		33
11	20-foot windspeed, mi/h			(12)	(10)	(10)	( )	
12	Wind adjustment factor			(.2)	(.2)	(.25)	( )	
13	Midflame windspeed, mi/h		M WS	2.4	2	2.5		79
14	Maximum slope, %		PCT S	38	0	0		80
15	Projection time, h		PT	10	10	10	10	81
16	Map scale, in/mi		MS					82
17	Map conversion factor, in/ch			.033	.033	.033	.033	
18	Effective windspeed, mi/h			3	2	2.5		

OUTPUT DATA

No.	Item	Key	Label					Reg. No.
19	Rate of spread, ch/h	[A]	ROS	4.3	.5	12	9.1	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1350	190	720		90
21	Fireline intensity, Btu/ft/s	[B]	INT	90	1	160		53
22	Flame length, ft	[R/S]	FL	3.8	0.5	4.5		54
23	Spread distance, ch	[C]	SD	43			91	42
24	Map distance, in	[R/S]	MD	1.4			3	43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 2

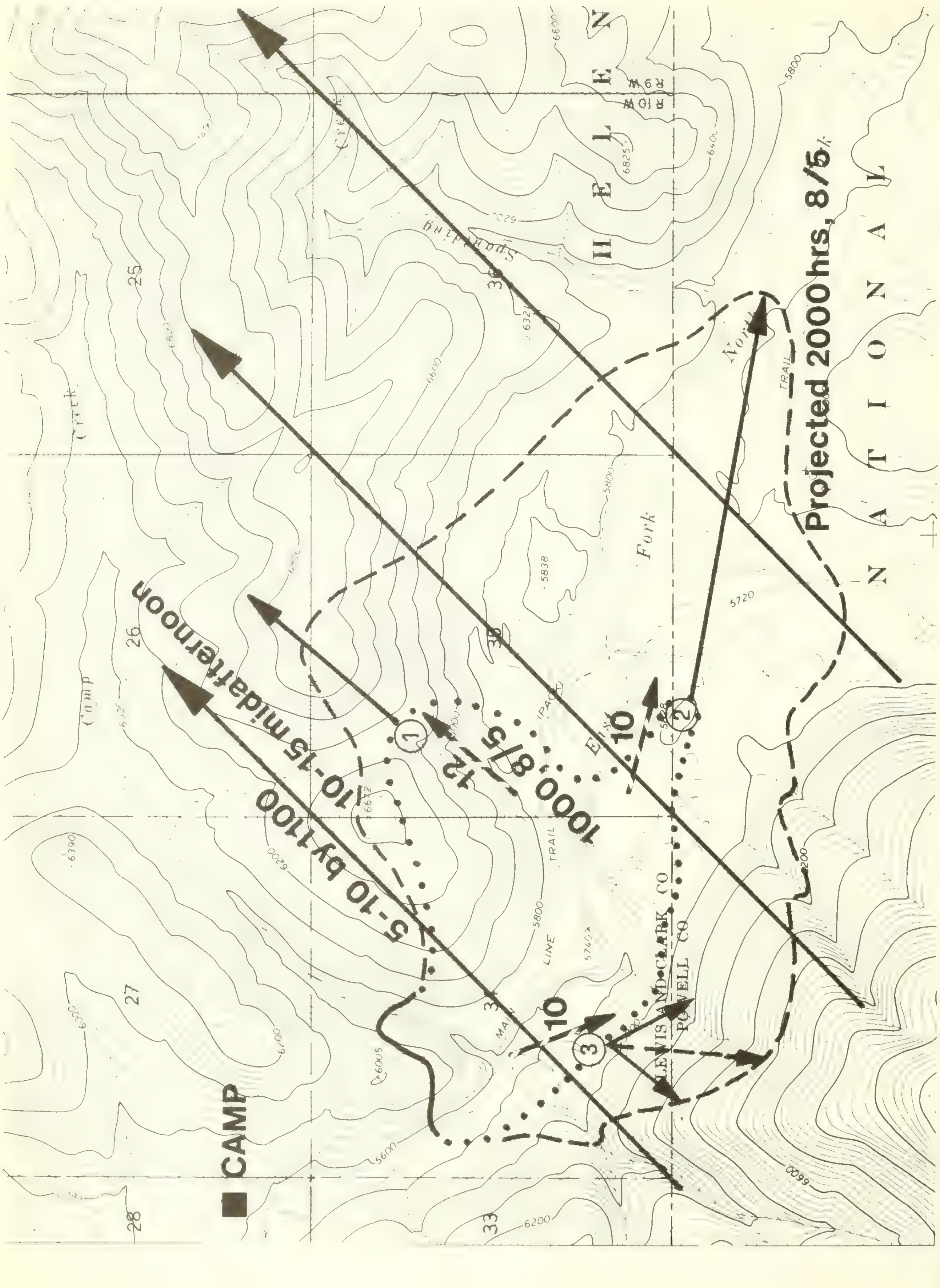
NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79 TIME 0930

PROJ. PERIOD DATE 8/5/79 PROJ. TIME FROM 1000 to 2000

INPUT DATA							TI-59 Reg. No.
1	Projection point		3	3			
2	Fuel model proportion, %		100				
3	Fuel model		10				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	2				60
5	Dry bulb temperature, °F	DB	82	Ditto			61
6	Relative humidity, %	RH	20				62
7	1 H TL FM, % Nomogram use	1H	7				28
8	10 H TL FM, %	10H					63
9	100 H TL FM, %	100H					30
10	Live fuel moisture, %	LIVE	100				33
11	20-foot windspeed, mi/h		(10)	( )	( )	( )	
12	Wind adjustment factor		(.2)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	2	0			79
14	Maximum slope, %	PCT S	0	40			80
15	Projection time, h	PT	10				81
16	Map scale, in/mi	MS	.033				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h		2	2			

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	2	2			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1300	1300			90
21	Fireline intensity, Btu/ft/s	[B]	INT	50	50			53
22	Flame length, ft	[R/S]	FL	2.7	2.7			54
23	Spread distance, ch	[C]	SD	20	20			42
24	Map distance, in	[R/S]	MD	.7	.7			43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52


Projected 2000hrs, 8/5
10-15 midafternoon
5-10 by 1100
1000, 8/5
12
10
10
CAMP
LEWIS AND CLARK CO
POWELL CO
N A T I O N A L
H E L E N
Spaulding
Creek
North
Fork
Camp
Creek
MAIN
TRAIL
LINE
TRAIL
(PACK)
R 10 W
R 9 W
25
26
27
28
33
34
35
36
1
2
3

Briefing Example

Overhead Team Briefing Notes 1400 Hours, August 5, 1979

1. *Previous Weather*

   Hot, dry, with clear skies. Daytime temperature highs to mid-80's on upper slopes, near 80 in drainage bottoms. Humidities down to 15 percent in valley bottom, near 20 percent on upper slopes. Winds upslope/up-canyon at 10 to 15 mi/h during heat of day, shifting to light downslope by 2100 hours. No change in sight for next several days. Near normal temperature and humidities have prevailed for the past 10 days, with no measurable precipitation. Daily inversion until approximately 1000 hours below 6,000 ft.

2. *Previous Fire Behavior*

   A. Fuels.—East flank of fire is advancing through an old burn (25 years old), which contains low brush up to 3 ft tall and patches of reproduction up to 20 ft tall, with branches near the ground to carry fire into crowns. The remainder of the fire is in mature timber, with medium to heavy loading of dead and down timber, which has varying amounts of live green understory containing about 100 percent moisture. Dead fine fuels are near 4 to 6 percent moisture content.

   B. Topography.—Broad valley bottom is flat to gently rising in an easterly direction. Slopes above the valley range from 25 to 70 percent, with average slope near 40 to 50 percent. Elevation of the valley bottom is approximately 5,600 ft and top of fire is near 6,800 ft.

   C. Weather.—Winds at time of origin (yesterday) were estimated at near 40 mi/h due to passage of a weak low-pressure system. Winds have generally been upslope/up-canyon during the day at speeds of 10 to 15 mi/h, changing to downslope 3 to 8 mi/h after 2100 hours daily.

   D. Behavior.—From start of fire until approximately 1800 hours last evening, the fire was very active, being pushed by winds near 40 mi/h. Crowning and spotting to one-half mile was common when fire entered crowns. Fire returned to the ground as winds slackened and evening conditions set in.

3. *Present Fire Status*

   Approximately 20 chains of control line has been constructed and held along the northwest flank. Remainder of fire is free to run, and will become active during heat of day. East side of fire will be most active as up-canyon winds blow against the lines.

4. *Predicted Fire Behavior*

   A. Fuel.—The fire has entered an old burn (25 years old) on the east flank where brush and ladder fuels are present. Remainder of fire is in mature conifer timber. Fuel moisture will range from 4 to 6 percent for fine dead fuels. Heavy loadings of down dead fuels are present throughout north and south flank areas ahead of fire.

   B. Topography.—Most active portion of the fire is in the flats along the river in the old burn. North side of fire is burning on slopes near 50 percent, while south flank is on slopes approximately 40 percent.

   C. Weather.—Present most recent weather forecast to overhead team.

   D. Behavior (v/s time).—

   Intensity - During heat of day intensity will be in a range that is marginal for direct attack with handtools (over 100 Btu/s/ft), especially in the old burn along east side of fire and on south-facing slopes. Flame lengths in these areas will be between 3 and 5 ft. North slopes will experience intensities of approximately 50 Btu/s/ft and flame lengths of 2 to 3 ft during the same period.

Rate of spread -	south slopes	= 4 chains per hour
	old burn	= 9 chains per hour
	north slopes	= 2 chains per hour

   Extreme fire behavior - Whirls may develop on lee sides of ridges or at canyon junctions. Expect whirlwinds in the burned area during heat of day. Individual trees or clumps will occasionally torch out where ladder fuels or heavy fuel loadings on the ground allow fire to enter crowns. Spotting may result up to one-fourth mile.

   Perimeter - Will continue to increase at a moderate rate until control lines are completed and held.

5. *Strategy Implications (v/s time)*

   A. Method of attack.—Direct attack with hand tools should be effective, with some possible difficulties along east flank in old burn. Careful use of retardant or timing attack to quiet periods of activity will be necessary. This portion of the perimeter will be most effectively worked at night when burning conditions are most favorable to control and down-canyon winds are blowing into burn area.

   B. Burnout/backfire.—Where unburned fuels remain inside control lines, burnout operations should proceed as quickly as possible to reinforce the narrow hand line. Winds will push fire against lines along the entire eastern flank during the day from 1000 hours until 2000 hours, making burnout very risky in that area; however, favorable winds blowing into the burn will persist along the western flank during this same period.

   Wind patterns will change near sunset permitting favorable burnout conditions on all areas of the fire except the western edge from 2100 hours until approximately 0900 hours next day.

   Temperature inversion will maintain favorable moisture/temperature conditions on upper slopes throughout the night. Humidities may hamper nighttime burnout in valley bottom.

   C. Fireline location.—Would recommend that control lines generally be positioned directly along edge of burn. Across steep draws or chutes, the line should be pulled back to safe and defensible terrain and the intervening fuels burned out as soon as conditions are favorable. Position control lines on backside of ridgecrests where fire is threatening ridgetops. Avoid sharp hooks in line or underslung line.

   D. Line standards.—Recommend well-constructed handline 2 to 3 ft in width. Such line should be effective in control if fuels on inside of line are burned out as line progresses or as quickly as favorable conditions exist. Where line is located through ladder fuels, prune low branches from trees as high as can be reached and within 100 ft of line. Avoid placing line through such fuels where practical.

   E. Success probability of manpower/equipment.—Good probability of success with ground forces along most of perimeter. May experience difficulty along east flank due to higher intensities and potential for spotting.

   F. Air operations.—Nighttime inversion will hold smoke in valleys until 1000 hours each morning, making air operations doubtful prior to 1000 hours. Ridgetop winds will be brisk during day and caution must be exercised at exposed helispots due to low level turbulence.

6. *Safety*

A. Reburn potential.—Areas of unburned fuels inside control lines have been scorched and dried and potential for reburn is moderate to high.

B. Risk locations.—East flank is an old burn. There is a potential for rapid spread, high intensities, and spotting. Know your escape routes!

C. High smoke concentrations.—Smoke will limit visibility to 300–500 yards in valley bottoms below 6,000 ft until 1000 hours each day. East flank of fire will likely remain smoky during day from active fire advance.

D. Reinforcement confidence level.—Feel that crews presently ordered or on the line should be sufficient to complete and hold lines by late tomorrow if present weather remains stable as predicted.

E. Air operations.—See 5-F.

EXERCISE 3

Day shift, August 6, 1979

Situation

It is now 2000 hours on August 5 and the night crews have departed for the line. The day crews being relieved will begin arriving in camp shortly. The fire weather meteorologist has given you an updated forecast for tomorrow, which indicates a possibility of cumulus buildup over the fire by early afternoon tomorrow, along with slightly warmer temperatures. Nighttime temperature inversion will hold smoke in the valleys below 6,000 ft until approximately 1000 hours daily. Line construction has progressed well today and night crews are hopeful of completing burnout in division I and most of division II as well as continuing construction of line along both flanks of the fire.

You have just returned from a helicopter reconnaissance of the fire with the plans chief and the meteorologist, and have helped to update the fire status map to accurately position the fire at 2000 hours. The fire has remained active throughout the day; however, it has not moved as far as earlier projected, due to effective use of helicopter water drops along fire front and on spots ahead of fire.

You must now project the spread of the fire along open portions of the line for tomorrow's day shift plans, working from the position you expect the fire at by tomorrow morning at 0600. The line overhead will be briefed at 0530 in the morning prior to shift change at 0600. You will be expected to present your fire behavior briefing. You must also prepare your fire behavior forecast for tomorrow's day shift plans and turn it in to the plans section by 2130, about 1-1/2 hours from now.

Three divisions of three sectors each are to be manned tomorrow, with divisions I and III lined and improvement and holding actions in progress. Division II will remain open through tonight, and crews will attempt to close that remaining portion of line as early as possible tomorrow.

As was determined in today's strategy session, it will be necessary to accomplish burnout and line improvement as early as possible if hand lines are to hold.

A spot fire was located during your helicopter reconnaissance about 1,000 ft ahead of the main fire on the east flank. It was estimated at less than one-quarter acre and did not appear to be rapidly spreading. It is inside and near the edge of the old burn in brushy fuels. There are no crews in the vicinity and it is doubtful that any could arrive at the spot before darkness sets in. The line boss is aware of the spot and has ordered helicopter water drops to be made as needed until darkness falls.

Assignment

1. Using your TI-59 calculator and fire behavior CROM, as well as all other information available to you, project the fire's spread during tomorrow's day shift from 0600 until 1800 hours. Prepare a map on which you have plotted fire spread. CAUTION: Have you used all the aids or intelligence available to you?
2. Prepare a fire behavior forecast for tomorrow's day shift (August 6), paying particular attention to strategies formulated by the overhead team.
3. Prepare a line briefing summary to be presented to line overhead before going on shift at 0530 in the morning. Pay particular attention to strategy implications. You may wish to use the fire characteristics chart to help make your points.

Summary of Weather Observations from Morrell Lookout

Date	Time	D.B. temp. (°F)	R.H. (%)	Winds (mi/h)
Aug. 5, 1979	1200	72	22	SW @ 8
	1400	82	18	SW @ 10 to 12
	1600	85	16	WSW @ 12 to 15 with gusts to 18
	1800	80	21	SW @10

WEATHER FORECAST

Day shift, August 6, 1979

NATIONAL WEATHER SERVICE, Missoula, Mont.
FORECASTER: Dave Goens
DATE AND TIME: August 5, 1979, 2100
(Tuesday)

FIRE: Blackfoot
LOCATION: Scapegoat Wilderness, Mont.
FORECAST NO.: 2

DISCUSSION: Upper level disturbance has passed east of the fire area. Pressures are building, winds are lighter, and conditions stabililizing. Look for fair skies and a little lighter winds. Daily inversion below 6,000 ft will persist until 1000 hours.

DAY SHIFT: August 6

WEATHER: Fair, with scattered cumulus buildup in vicinity of fire during the afternoon.

TEMPERATURE: Lower slopes near 90° F
Upper slopes near 85° F

HUMIDITY: Minimum near 12 to 15%

RIDGETOP WIND: SW 10 to 15 mi/h

SLOPE WINDS: Upslope by 1030 hours, 5 to 8 mi/h, chance of some gusts to near 15 to 18 mi/h mid- to late afternoon.

OUTLOOK FOR NEXT SHIFT: Night shift August 6
Clear with light winds and fair to good humidity recovery.

FURTHER OUTLOOK: (36 to 48 hours) Dry with above normal temperatures.

Summary of Strategy Session, August 5, 1979

Following are key points agreed to by the fire overhead team at the August 5, 1979, strategy session:

1. Continue to drive line rapidly in both directions from anchor point near the fire's origin. Work a pincer attack to cut off head of fire as flanking lines are completed.
2. Use direct attack in all cases where it is safe and effective.
3. Only hand lines will be used due to wilderness designation. Lines will be dug to bare soil and must be 2 to 3 ft in width.
4. Line improvement, particularly burnout, *must* proceed as quickly as possible after line is constructed. Take advantage of most favorable conditions to line and burnout difficult areas of the fire.
5. Plans section must analyze crew capabilities and condition to use most experienced and rested crews to drive line and burnout. Other crews will be used to hold constructed line.
6. Retardant will be used sparingly because of cost involved; however, it is available if needed.
7. Aerial and ground reconnaissance of a secondary control line location on the east side of the fire will be made immediately. This location, if satisfactory, will be used if fire overcomes initial containment efforts.
8. Avoid placing line through ladder fuels; however, if necessary, prune lower limbs from trees as high as reachable within 100 ft of the fireline. Do not concentrate pruned branches near fireline.
9. Crews will hike from base camp to the fireline and return using the main line trail through cooled portions of the fire, or along existing fireline. Night shift crews should relieve day shift in time to permit return to camp during daylight.
10. Fire behavior officer must keep a close watch on burnout conditions and keep line people advised of timing and locations where burnout may proceed.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 3

NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79 TIME 2000

PROJ. PERIOD DATE 8/6/79 PROJ. TIME FROM 0600 to 1100

				Two-fuel-model concept				TI-59 Reg. No.
INPUT DATA								
1	Projection point			1	1			
2	Fuel model proportion, %			25	75			
3	Fuel model			8	5	8&5		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE*	3				60
5	Dry bulb temperature, °F		DB	60				61
6	Relative humidity, %		RH	50	Ditto			62
7	1 H TL FM, %	from TI-59	1H	9.6				28
8	10 H TL FM, %	1.5% wetter than afternoon	10H	5				63
9	100 H TL FM, %		100H	6				30
10	Live fuel moisture, %		LIVE	–	100			33
11	20-foot windspeed, mi/h			(0)	(0)	( )	( )	
12	Wind adjustment factor			(–)	(–)	( )	( )	
13	Midflame windspeed, mi/h		M WS	0				79
14	Maximum slope, %		PCT S	0				80
15	Projection time, h		PT	5	5	5		81
16	Map scale, in/mi		MS	2.64				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h			0				
OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	.2	.4	.35		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	167	227			90
21	Fireline intensity, Btu/ft/s	[B]	INT	1	2			53
22	Flame length, ft	[R/S]	FL	.3	1			54
23	Spread distance, ch	[C]	SD	.9	1.9	1.8		42
24	Map distance, in	[R/S]	MD			.1		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

* Shade 3 and wind zero because of inversion and smoke.
Temp. est. 60° and RH 50% average for the projection period.

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 3

NAME OF FIRE Blackfoot   FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79   TIME 2000

PROJ. PERIOD DATE 8/6/79   PROJ. TIME FROM 1100 to 1400

Two-fuel-model-concept

INPUT DATA							TI-59 Reg. No.
1 Projection point			2	2			
2 Fuel model proportion, %			25	75			
3 Fuel model			8	5	8&5		
4 Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	2	0			60
5 Dry bulb temperature, °F		DB	90				61
6 Relative humidity, %		RH	12				62
7 1 H TL FM, %	Used TI-59	1H	2.6	2.0			28
8 10 H TL FM, %		10H	3.2	2.5			63
9 100 H TL FM, %		100H	5	–			30
10 Live fuel moisture, %		LIVE	–	100			33
11 20-foot windspeed, mi/h			(15)	(15)	( )	( )	
12 Wind adjustment factor			(.2)	(.25)	( )	( )	
13 Midflame windspeed, mi/h		M WS	3	3.8			79
14 Maximum slope, %		PCT S	0	0			80
15 Projection time, h		PT	3	3	3		81
16 Map scale, in/mi		MS	2.64	2.64			82
17 Map conversion factor, in/ch							
18 Effective windspeed, mi/h							

OUTPUT DATA							
19 Rate of spread, ch/h	[A]	ROS	2	21	16		88
20 Heat per unit area, Btu/ft^2	[R/S]	H/A	232	775			90
21 Fireline intensity, Btu/ft/s	[B]	INT	6	294			53
22 Flame length, ft	[R/S]	FL	1	6			54
23 Spread distance, ch	[C]	SD			49		42
24 Map distance, in	[R/S]	MD			1.6		43
25 Perimeter, ch	[D]	PER					40
26 Area, acres	[R/S]	AREA					89
27 Ignition component, %	[E]	IC					44
28 Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 3

NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard

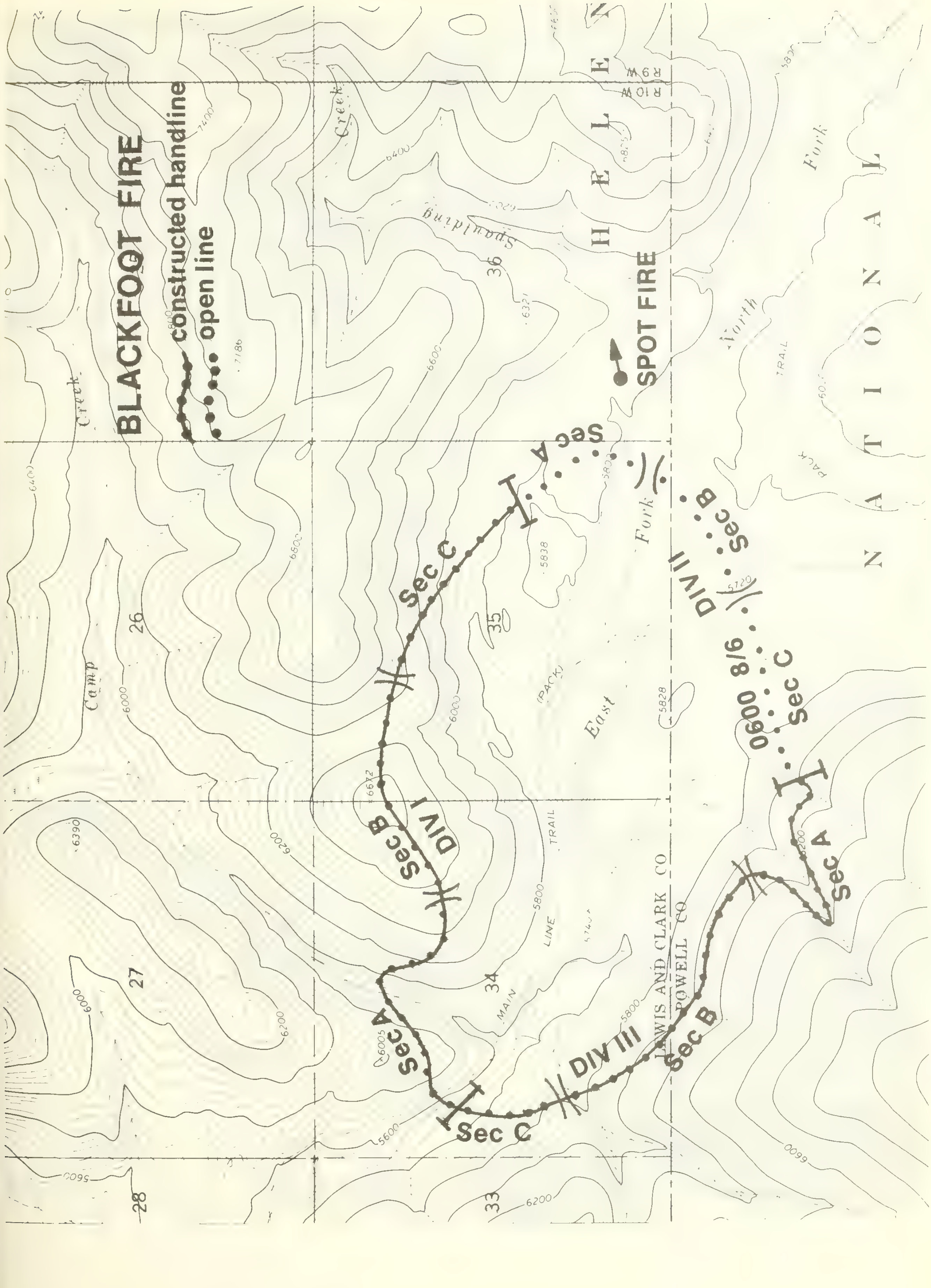
DATE 8/5/79 TIME 2000

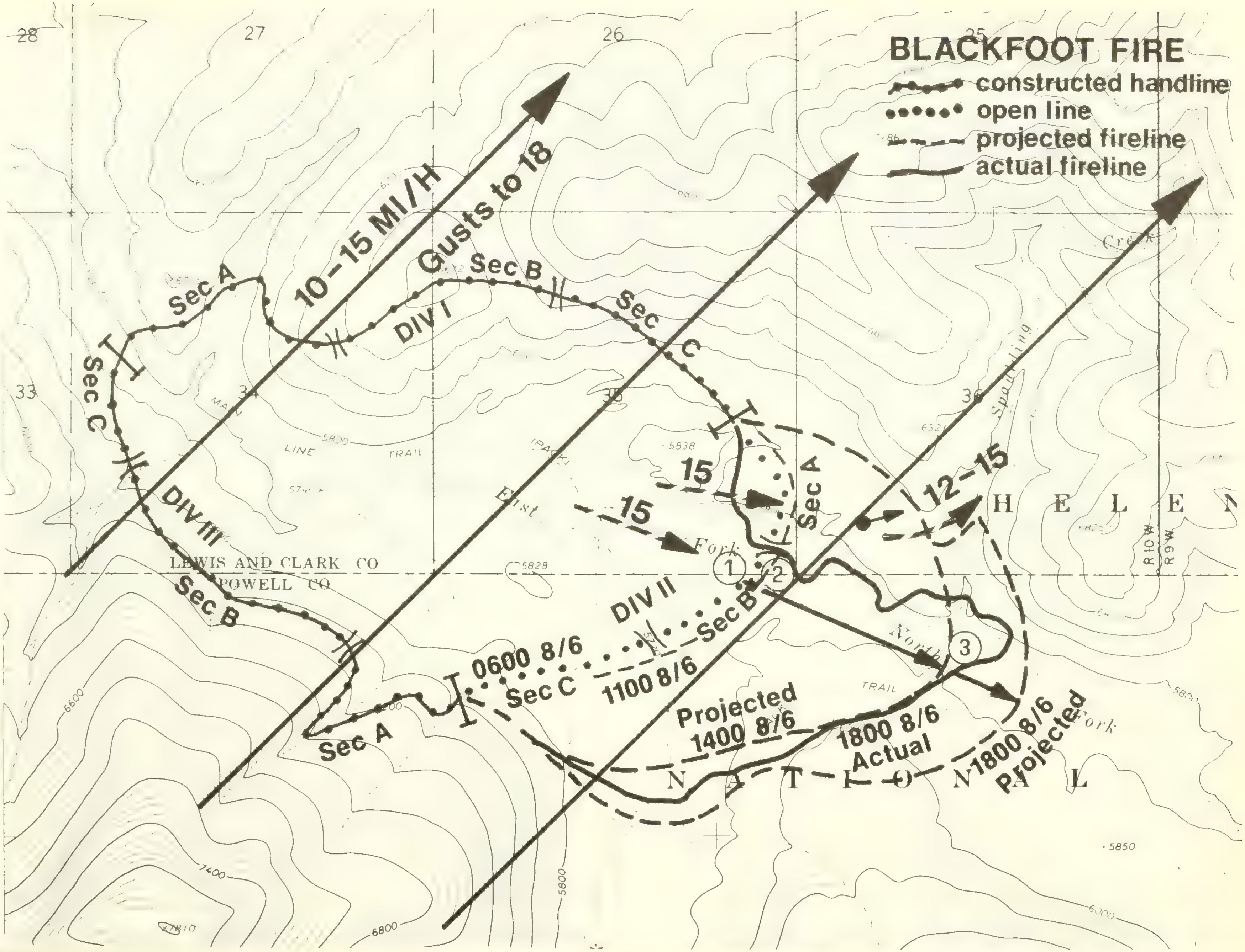
PROJ. PERIOD DATE 8/6/79 PROJ. TIME FROM 1400 to 1800

Fire is expected to enter fuel model 10 at 1400.

INPUT DATA							TI-59 Reg. No.
1	Projection point		3				
2	Fuel model proportion, %		100				
3	Fuel model		10				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	3				60
5	Dry bulb temperature, °F	DB	90				61
6	Relative humidity, %	RH	12				62
7	1 H TL FM, %	1H	2.8				28
8	10 H TL FM, %	10H	3.5				63
9	100 H TL FM, %	100H	5				30
10	Live fuel moisture, %	LIVE	100				33
11	20-foot windspeed, mi/h		(15)	( )	( )	( )	
12	Wind adjustment factor		(.2)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	3				79
14	Maximum slope, %	PCT S	0				80
15	Projection time, h	PT	4				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch		–				
18	Effective windspeed, mi/h		–				

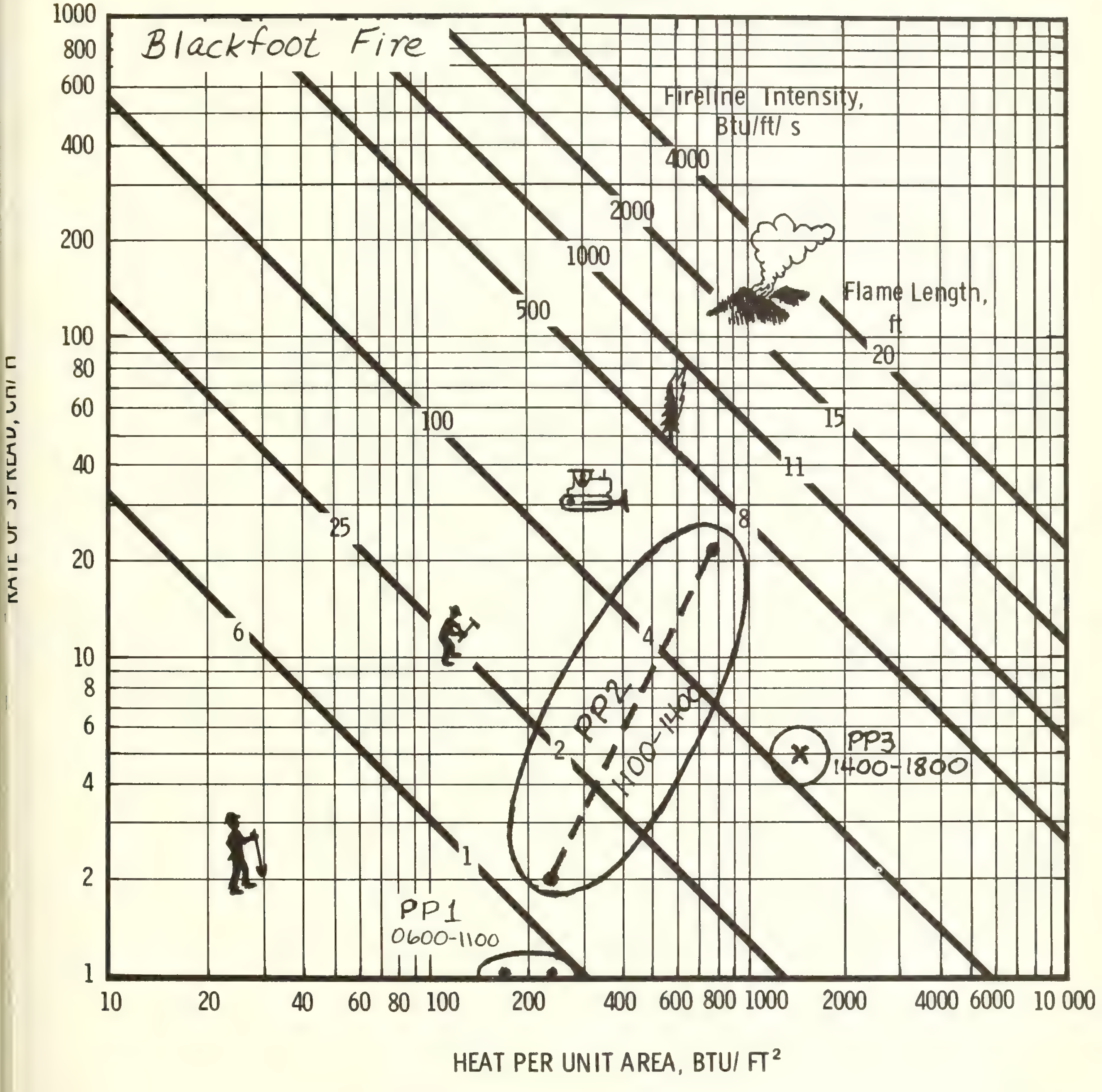
OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	5				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1474				90
21	Fireline intensity, Btu/ft/s	[B]	INT	146				53
22	Flame length, ft	[R/S]	FL	4				54
23	Spread distance, ch	[C]	SD	21.6				42
24	Map distance, in	[R/S]	MD	0.7				43
25	Perimeter, ch	[D]	PER	–				40
26	Area, acres	[R/S]	AREA	–				89
27	Ignition component, %	[E]	IC	42				44
28	Reaction intensity, $Btu/ft^2/min$	[R/S]	IR	–				52


BLACKFOOT FIRE
constructed handline
open line
SPOT FIRE
DIV I
Sec A
Sec B
Sec C
DIV II
Sec A
Sec B
Sec C
0600 8/6
DIV III
Sec A
Sec B
Sec C
LEWIS AND CLARK CO
POWELL CO
MAIN LINE TRAIL
PACK TRAIL
Camp Creek
Spaulding Creek
East Fork
North Fork
R10W R9W
26
27
28
33
34
35
36


BLACKFOOT FIRE
constructed handline
open line
projected fireline
actual fireline
10–15 MI/H
Gusts to 18
Sec A
Sec B
Sec C
DIV I
DIV II
DIV III
15
15
12–15
0600 8/6
1100 8/6
Projected
1400 8/6
1800 8/6
Actual
1800 8/6
Projected
LEWIS AND CLARK CO
POWELL CO
MAIN LINE TRAIL
East Fork
North Fork
Spaulding Creek
HELENA NATIONAL
R10W R9W
28
27
26
25
33
34
35
36
5838
5828
5800
5850
6000
6600
6800
7400

FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)



FIRE BEHAVIOR FORECAST NO. 2

Solution Example

NAME OF FIRE: Blackfoot
FOREST: Lolo
TIME AND DATE
FORECAST ISSUED: 2100 hours 8/5/79

PREDICTION FOR: Day SHIFT
SHIFT DATE: August 6, 1979

SIGNED: ______________________
FIRE BEHAVIOR OFFICER

WEATHER SUMMARY: See attached weather report.

Be alert for cumulus buildup in the vicinity of the fire after 1400 hours that may cause strong, gusty, erratic winds. (Morrell Lookout alerted to warn of cumulus buildup.)

FIRE BEHAVIOR:

General: Severe burning conditions continue to exist in the old burn on east side of fire. Very dry fuels will keep fire active in all unlined sectors. High temperatures and low relative humidity increase occurrence of spotting potential to one-fourth mile. Whirls likely to form on lee side of ridges and in blackened area during late afternoon-early evening. Fuels inside line will continue to make uphill runs in draws and on steep slopes. Flame lengths of 6 ft will be common in brush fuels along east flank until old burn is completely consumed by approximately 1400 hours. Potential for reburn is moderate to high in areas where crowns are scorched by ground fire. ROS up to 21 chains/hour in brush fuels.

Specific:

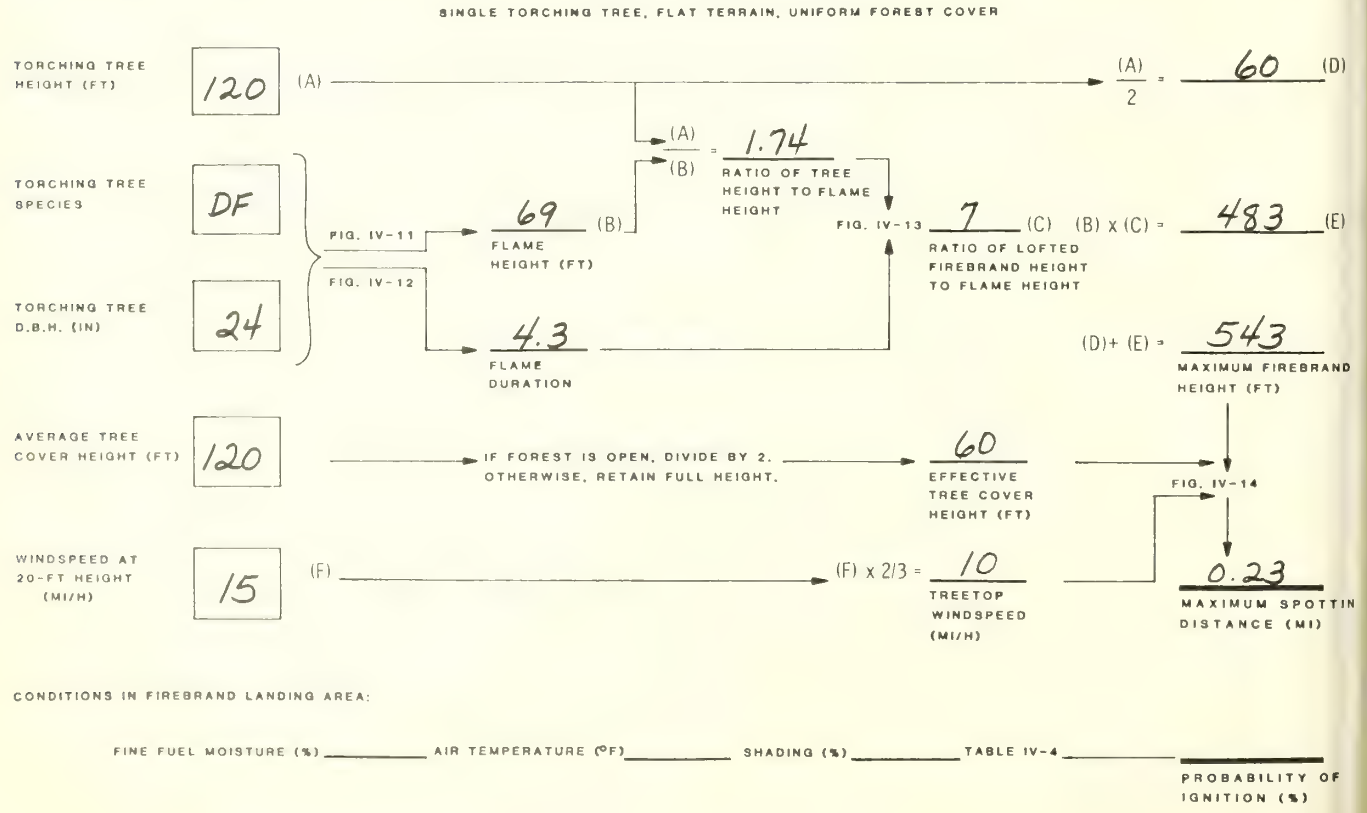
Division I.—Be alert for spots across line. Favorable burnout conditions above inversion (approx. 6,000 ft) until 1100 hours when developing upslope winds will call for extreme caution if burnout is to proceed. Below 6,000 ft in sector C high humidity will hamper burnout until inversion breaks about 1000 hours, then increasing up-canyon winds will make burnout risky. Be alert for wind shift.

Division II.—Ladder fuels will cause torching, with spotting to one-fourth mile. Fire will be intense in brush fuels, with flame lengths of 6 ft; too hot for crews to work near fire. ROS up to 21 chains/hour will occur. Position lookouts to alert crews if safety is threatened. Unfavorable conditions in all sectors for entire shift due to high RH until inversion is lifted by up-canyon winds which will then push fire against control lines. Where burnout must proceed, use extreme caution to avoid creating large amounts of heat near the line.

Division III.—Favorable burnout conditions above 6,000 ft until 1100 hours. Portions of sectors B and C where burnout remains to be done below 6,000 ft will have favorable conditions after inversion is broken about 1000–1100 hours when winds will begin to blow into fire or parallel to control line. Burnout should be complete by 1300 hours to avoid strong afternoon upslope winds. Avoid generating large amounts of heat in draws in sector A. Watch for spots above these draws.

AIR OPERATIONS: Temperature inversions will hold smoke in valleys below 6,000 ft until 1000 hours stopping low level operations and helicopter access to base camp. Ridgetop winds of 15 to 20 mi/h will cause low level turbulence at ridgetop helispots.

SAFETY: Potential for extreme fire behavior throughout day. Be sure of escape routes and post lookouts. Watch for rolling debris and falling snags.



Shift Briefing for Line Overhead Example

Day shift, August 6, 1979

I. What has fire done since you left line?
Fire has been relatively quiet during the night with no major runs or unexpected behavior due to cold temperatures, humidities up to 70 percent, and favorable night winds blowing into the fire on the open east flank.

II. Reasons for previous behavior.
After initial run of fire, which was pushed by 40 mi/h winds, the rates of spread have decreased due to return of more normal wind velocities of 10 to 15 mi/h during the day. High temperatures and low humidities, resulting in very low fuel moistures, have made conditions favorable for continued spread. The fire has been most active along the east flank where it is burning in flashy brush fuels, with ladder fuels causing some spotting ahead of the fire. This area of the fire is also affected by strong up-canyon winds during the heat of the day.

III. Weather
Continuation of hot, dry weather. Below normal precipitation for the past 6 weeks, with no moisture in sight. (Read today's weather prediction.)

IV. Fuels
Division II is presently burning in an old burn with 75 percent brush and 25 percent short needle conifer saplings and poles up to 25 ft in height. The unburned remnants of this old burn will be consumed by 1400 hours today when the fire will enter a mature stand of Douglas-fir, larch, and lodgepole. The fire will be much easier to contain in the mature timber stands because intensities and spread rate will be reduced to levels that will permit direct attack this afternoon. Fuel moisture from the NFDRS D9b form for the AFFIRMS station at Lincoln, Mont. (18 miles south) are:

Saturday, August 4, 1979:

1 hr TL = 6%
10 hr TL = 10% = 12% at fire
1,000 hr TL = 14% = 16% at fire

V. Topography
Most active area of the fire is presently confined to flat valley bottom, but steeper side slopes up to 60 percent surround the fire. The narrow steep-sided canyon of Spaulding Creek is in the path of the fire about one-half mile ahead.

VI. What is fire forecasted to do and when?
(Refer to today's fire behavior broadcast.)

VII. Safety

A. Extreme fire behavior potential
  1. Signals to watch for:
     - A shift of wind direction
     - An increase in windspeed
     - Downhill line construction
     - Working near heads of draws or brushy ravines
     - Spots across the line
     - Reburn of scorched fuels within the fireline
     - Whirlwinds on lee side of ridges or in the blackened area

B. Expectations of line overhead (what help do I need?)
- Contact FBO to report unusual or severe behavior, wind shifts, cumulus buildup, etc. Intelligence officer and line scouts will be asked to take weather observations on the fire line and radio them to the FBO or Plans.
- Need feedback from line people on accuracy of weather and fire behavior predictions.

Rothermel, Richard C. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 161 p.

This manual documents procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. Contains instructions for obtaining fuel and weather data, calculating fire behavior, and interpreting the results for application to actual fire problems.

KEYWORDS: fire behavior prediction, fire spread, fire intensity, fire growth

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

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Logan, Utah (in cooperation with Utah State University)

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Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-144

July 1983

Forest Habitat Types of Eastern Idaho-Western Wyoming

Robert Steele, Stephen V. Cooper, David M. Ondov, David W. Roberts, and Robert D. Pfister

THE AUTHORS

ROBERT STEELE was research forester on the Forest Ecosystems and the Douglas-fir and Ponderosa Pine Ecosystems Research Work Units. He worked full time on development of forest habitat type classification in Idaho and Wyoming. He was primary analyst and author of the *Pseudotsuga* and *Abies* series as well as supplementary sections of the manuscript. He joined the Intermountain Station in 1972 as forester on the Forest Ecosystems Research Work Unit, which conducted most of the work treated herein. He earned a B.S. degree in forest management and an M.S. degree in forest ecology at the University of Idaho.

STEPHEN V. COOPER was an assistant range ecologist, University of Nevada, and performed initial field sampling and analysis for a portion of the study area while a graduate student at Washington State University. Under a cooperative program with the Bureau of Indian Affairs, he sampled forest habitats on the Wind River Indian Reservation. He was supporting analyst for all series, and author of the *Picea engelmannii*, *Pinus contorta*, *P. albicaulis*, and *P. flexilis* series as well as the climate and physiography sections of the manuscript. He earned a B.S. and an M.S. in biology from Union College and the State University of New York, respectively, and a Ph.D. in botany from Washington State University.

DAVID M. ONDOV was a forestry technician with the Forest Ecosystems Research Work Unit in Missoula and did much of the field sampling during the course of this project. He had primary responsibility for constructing the necessary computer programs and processing of data. He also shared responsibility for developing the preliminary habitat type classification. He earned a B.S. degree in forestry at the University of Montana in 1976.

DAVID W. ROBERTS was a forestry technician with the Forest Ecosystems Research Work Unit in Missoula and a team member on field sampling of the Shoshone National Forest. He was primary analyst and developer of the habitat type similarity analysis and handled much of the computer programing procedures and data processing. He earned a B.S. in forestry and an M.S. in forest ecology from the University of Montana.

ROBERT D. PFISTER was principal plant ecologist and leader of the Forest Ecosystems Research Work Unit and initiated and directed this classification project. He had a major role in reviewing and shaping the development of this classification and manuscript. He joined the Intermountain Station staff in 1961 as a research forester in western white pine silviculture in northern Idaho. He holds B.S. and M.S. degrees in forest management from Iowa State University and Oregon State University, respectively, and a Ph.D. in botany from Washington State University.

ACKNOWLEDGMENTS

Financial support for this study was provided by the Intermountain Region of the Forest Service, U.S. Department of Agriculture, the Bridger-Teton National Forest, and the Shoshone National Forest through memoranda of understanding with the Intermountain Forest and Range Experiment Station. The Bureau of Indian Affairs provided funding for a concurrent study, the results of which are included in this report.

Many people have assisted in various ways. Dr. Edward F. Schlatterer (Intermountain Region) provided data taken during reconnaissance of the Greys and Hoback River drainages. Dr. Jan A. Henderson (Utah State University) provided data from a concurrent habitat type classification effort in Utah and adjacent Idaho. Mert Lombard (Bureau of Land Management) gave us data from timber inventory plots within the study area. Dr. Don G. Despain (National Park Service) provided supplementary plot data from Yellowstone National Park. Cecil Brown (Idaho Fish and Game) furnished data from concurrent studies critical to wildlife. Dr. George R. Hoffman (University of South Dakota) provided data from his study (Hoffman and Alexander 1976) in the Bighorn Mountains, and staff on the Targhee National Forest also furnished plot data. Dr. Al Galbraith and Al Collotzi (Bridger-Teton National Forest) and Ollie L. Scott (Shoshone National Forest) coordinated logistical support during various portions of the field work. Dr. Stephen F. Arno (Intermountain Station) made several helpful reviews in relation to similar work he conducted in Montana (Pfister and others 1977). Others who reviewed the manuscript include Earle F. Layser (Consultant, Land Management Services), Dr. Edward F. Schlatterer (Intermountain Region), Ollie L. Scott (Shoshone National Forest), Andy P. Youngblood (Bridger-Teton National Forest), Dr. George R. Hoffman (University of South Dakota), Dr. Robert M. Reed (Oak Ridge National Laboratory), and Dr. Don G. Despain (National Park Service).

Specialists in other fields provided supplementary information. Dr. Douglass M. Henderson (University of Idaho), Peter F. Stickney (Intermountain Station), and Klaus Lackschewitz (University of Montana) helped identify several difficult plant taxa. Dr. Marcia Wicklow-Howard (Boise State University) and Roger Rosentretor (University of Montana graduate student) identified lichens collected in our sample plots. Likewise, Alma Steele (Boise Public Schools) identified numerous mosses and Dr. Won Shic Hong (College of Great Falls) named the liverworts. James Clayton (Intermountain Station) and Jeff Lelek (University of Montana) identified soil parent materials.

RESEARCH SUMMARY

A land-classification system based upon potential natural vegetation is presented for the forests of eastern Idaho-western Wyoming. It is based on reconnaissance sampling of about 980 stands. A hierarchical taxonomic classification of forest sites was developed using the habitat type concept. A total of six climax series, 58 habitat types, and 24 additional phases of habitat types are defined. A diagnostic key is provided for field identification of the types based on indicator species used in development of the classification.

In addition to site classification, descriptions of mature forest communities are provided with tables to portray the ecological distribution of all species. Potential productivity for timber, climatic characteristics, surface soil characteristics, and distribution maps are also provided for most types. Preliminary implications for natural resource management are provided, based on field observations and current information.

CONTENTS

APPENDIXES:

LIST OF FIGURES:

LIST OF TABLES:

Forest Habitat Types of Eastern Idaho-Western Wyoming

Robert Steele, Stephen V. Cooper, David M. Ondov, David W. Roberts, and Robert D. Pfister

INTRODUCTION

The forests of eastern Idaho and western Wyoming oc-
cupy an area of complex geology, varied climatic patterns, and merging floras. The resulting vegetation is a diverse mosaic confounded by periodic disturbance. Yet those who administer these lands must reduce this diversity into manageable units. Situations such as this have led people to classify forests for specific purposes, but unfortunately a classification designed for one purpose rarely suits another. A forest serves many needs, therefore its managers should have a classification system that is not structured for one purpose but rather one that serves a variety of management needs.

Classifying forest land by habitat type has proven useful in forest management and research; application has expanded rapidly over the last decade (Layser 1974). Classifications have now been developed for about 20 areas in the western United States (Pfister 1976). This increasing use reflects recognition of the need to emphasize management of ecosystems rather than individual resources. Specialists in different resources also recognize the need to have a common medium for communication, management, and research.

The first habitat type system of site classification was developed over a 20-year period by Daubenmire (1952) for the forests in northern Idaho and eastern Washington. Later, R. and J. Daubenmire (1968) refined their original system. Since then, their approach has served as a model for classification of other areas.

Within the eastern Idaho-western Wyoming area, three earlier studies had provided classification for parts of the area. Reed (1969) defined five rather broad habitat types in the Wind River Range of Wyoming. Cooper (1975) covered the Teton division of the Bridger-Teton National Forest, most of the Targhee National Forest, Yellowstone National Park, and Grand Teton National Park. Henderson and others (1976 unpubl.) developed a habitat type classification for northern Utah, which extended into southeastern Idaho. Still much of the eastern Idaho-western Wyoming area had not been covered and the three existing studies needed to be consolidated into an overall habitat type classification.

In 1976, the Intermountain Region and the Intermountain Forest and Range Experiment Station of the USDA Forest Service began a cooperative study to classify forest habitats in eastern Idaho and western Wyoming. That summer, two field crews (led by Steele and Ondov) sampled areas on the Bridger-Teton, Caribou, and Targhee National Forests not covered in the previous studies and did some additional sampling in areas previously covered. Data from this sampling were combined with data from the previous studies in the area and a preliminary classification (Steele and others 1977 unpubl.) was developed and field tested. In 1978, the same two crews sampled the Shoshone National Forest and did more fill-in sampling in the remaining area. Also, a third crew (led by Cooper) sampled the Wind River Indian Reservation, which borders the Shoshone National Forest. Data from: (1) these samplings, (2) Cooper's (1975) thesis, (3) Reed's (1969) thesis, (4) Henderson and other's (1976 unpubl.) stands and (5) selected stands in central Idaho (Steele and others 1981), Montana (Pfister and others 1977) and Wyoming's Bighorn Mountains (Hoffman and Alexander 1976) were combined for analysis and classification of habitat types in a second preliminary classification (Steele and others 1979 unpubl.) and in this report. Only data from within the study area, however, were used in the charts and tables presented herein.

The area covered by this classification extends roughly from Monida Pass on Interstate 15 in Clark County, Idaho, southwestward to the Utah and Nevada borders, and eastward through the contiguous forests of Wyoming (figs. 1, 2). Isolated forests farther east in the Bighorn Mountains (Hoffman and Alexander 1976) and Medicine Bow Mountains (Wirsing and Alexander 1975) have been previously classified. The isolated forests in Owyhee County, Idaho, are inadequately sampled for inclusion in this classification and possibly relate to unsampled forests to the south and west. Other adjacent areas have been treated in previous studies (Pfister and others 1977; Henderson and others 1976 unpubl.; Steele and others 1981). This study includes most of the land in four national forests, part of one other national forest, two national parks, one Indian reservation, and adjacent forest land regardless of ownership. Floodplains dominated by broadleaved trees and communities dominated by *Juniperus osteosperma* or *Acer grandidentatum* are not included. Likewise, pure stands of *Populus tremuloides*, which are described by Youngblood (1979), are only noted herein at the series level.

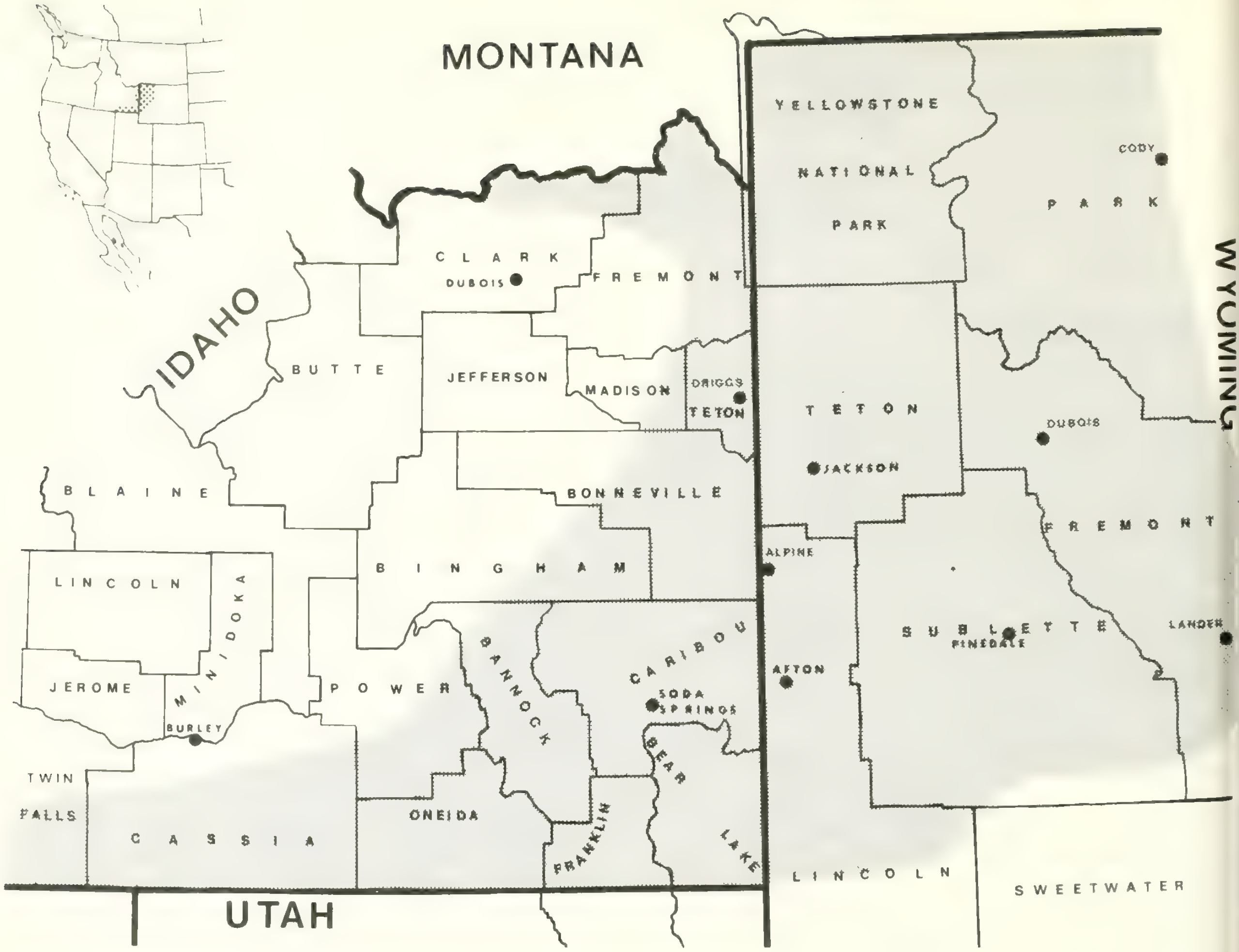


Figure 1.—Area covered by this classification (shaded) showing States, counties, and some towns.

Objectives and Scope

The objectives of this study were:

1. To develop a habitat type classification for the forested lands of eastern Idaho and western Wyoming based on the potential climax vegetation.

2. To describe the general geographic, topographic, climatic, and edaphic features of each type. (See glossary in appendix G for definitions.)

3. To describe the late seral and climax plant communities characteristic of each habitat type.

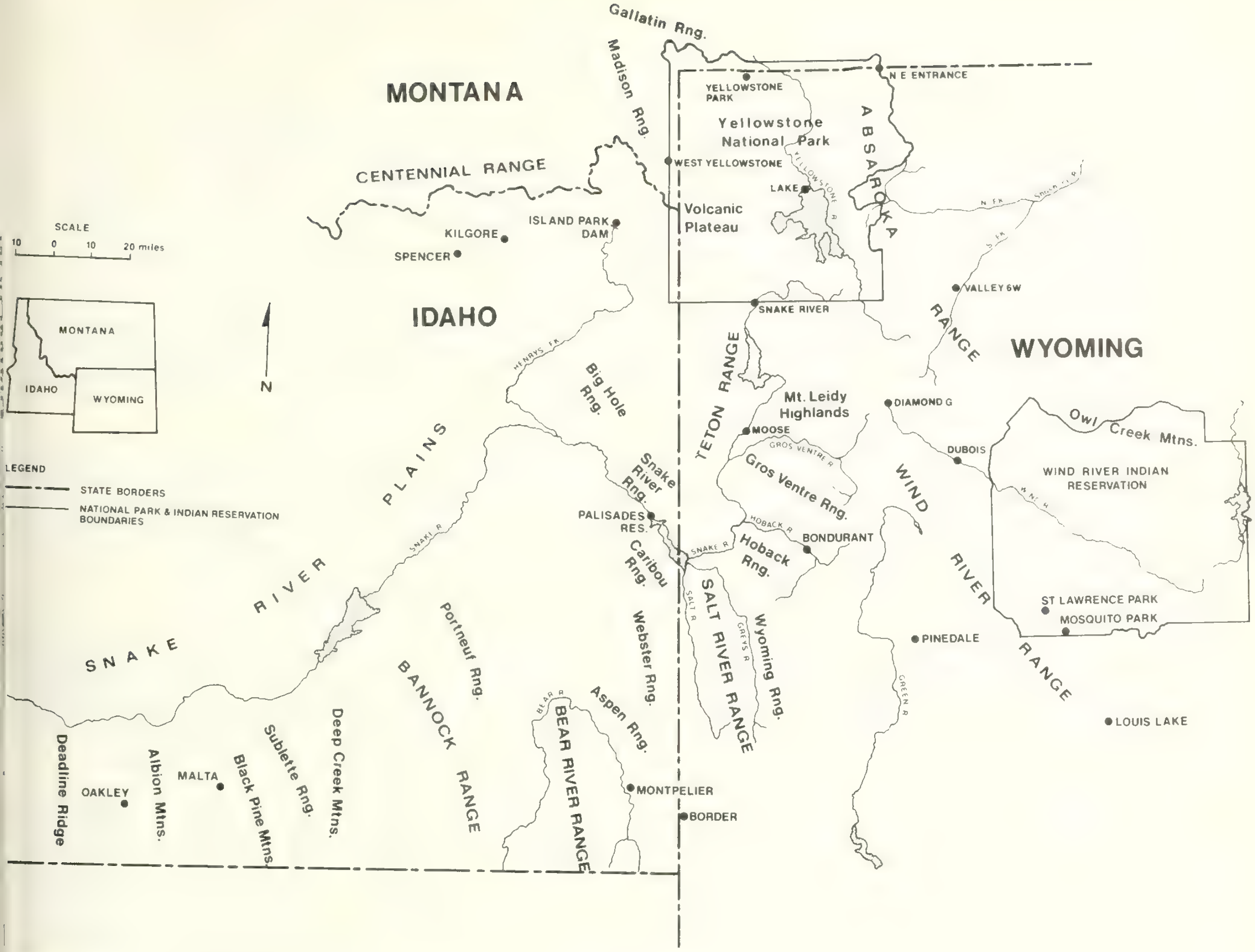
4. To provide information on successional development, timber productivity potential, and other biological observations of importance to land managers.

5. To further develop and test a reconnaissance-plot method of data gathering (Pfister and Arno 1980) that allows development of a habitat type classification with minimum time and cost.

METHODS

Field Methods

The objective of collecting field data was to efficiently sample a full range of environmental conditions in eastern Idaho and western Wyoming forests. Random and systematic sampling procedures were rejected as inefficient and impractical for this study. The approach we used is similar in concept to the "subjective without preconceived bias" method supported by Mueller-Dombois and Ellenberg (1974). This method was applied to all three steps of plot



gure 2.—Area covered by this classification showing major mountain ranges, ainage patterns, and selected weather stations.

cation: (1) selecting road transects, (2) selecting stands, ɨd (3) placing the plot within the stand. With this ap- oach, plots were not selected by the probable place- ɪent of a stand within any classification nor by apparent ɪplicability to specific management problems.

levational road transects were selected to reflect the ɪnge of environmental conditions found in the forest. ɪually the team leader made note of possible sampling ɪes as he reconnoitered the transect. Brief stops were ɪade to inspect undergrowth composition. The overstory ɪd general undergrowth patterns were observed en route. ɪ the return trip, mature stands that best represented ɪe different kinds of plant communities for that transect ɪre selected for sampling.

ɪots were located within a homogeneous portion of ɪlected stands to provide a representative sample. To do ɪs, the team leader examined the stand from the road. ɪr uneven-aged stands, the largest tree or group of trees ɪ the stand was chosen as the plot center. For even-aged ɪnds the plot was centered in the largest homogeneous expanse of tree canopy. Upon reaching plot center, the surrounding area was examined to insure that the sample plot would, in fact, represent the stand. If the sample plot included ecotones, obvious microsites, or severe disturbance, it was relocated to avoid those conditions.

Plot center for a 375 m^2 (0.093 acre) circular plot was marked with a labeled wooden stake. The plot center was referenced to roadside features to enable revisitation during the study.

Trees more than 4.5 feet (1.4 m) tall were tallied by 2-inch d.b.h. classes according to species. Trees 0.5 to 4.5 feet (0.15 to 1.4 m) in height were recorded by species in a 50 m^2 (0.012 acre) circular plot.

Amounts of all vascular plant species were estimated by seven canopy-coverage classes (+ = present in stand but not in plot, T = 0–1% coverage, 1 = 1%–5%, 2 = 5%–25%, 3 = 25%–50%, 4 = 50%–75%, 5 = 75%–95%, 6 = 95%–100%). For maximum efficiency, these coverages were estimated within the entire 375 m^2

(0.093 acre) plot instead of the usual series of small quadrats (Daubenmire 1959). With practice and coordination among the samplers (including practice layouts within the plot representing areas of 1%, 5%, and 25%), it is possible to visualize and reliably estimate coverage of all the plants by this one method. Accuracy may be somewhat less than where coverages are estimated in small quadrats, but the number of stands sampled in a day can be at least doubled, thus providing better sample coverage of the region. These coverage-class estimates can be used directly in association tables or ordinations.

All unidentified plants on each plot were collected and preserved for later identification or verification. Many plants in flower were also collected for voucher specimens and deposited in the herbarium of the Intermountain Forest and Range Experiment Station at Boise (BOIS).

A relatively free-growing tree of each species present was measured for height, age, and diameter in order to estimate site potential by species. Suitable site trees for each species were not always available, especially in dense stands. In those cases, no site data for those species were collected.

Plot aspect was measured with a compass to the nearest 5 degrees. Degrees of slope and tree heights were measured with a clinometer; altitudes were estimated with a pocket altimeter or from USGS 7½- or 15-minute topographic maps.

Thicknesses of litter, fermentation, and humus layers were averaged from measurements at three random locations in the plot. Samples of the upper 20 cm (ca. 8 inches) of mineral soil were collected for laboratory analysis of percentage of coarse fraction and pH. Samples of the parent material were also collected when available.

Observations were made on fire history, insect and disease occurrence, animal use, and the topographic and soil moisture relationships of the sampled stand to adjoining stands. This latter observation proved valuable during analysis of relationships between plant community types and environmental gradients.

Office Methods

Development of the classification followed the general procedures outlined below.

1. Immediately after each field season, possible types were listed based on our field observations. New situations not conforming to previous classifications from adjoining areas were noted and briefly described.

2. Voucher specimens of plants were identified and some were sent to other herbaria (ID, MRC, MONTU) for verification. Unknown vegetative material was compared with identified specimens. All positive identifications were entered on the field forms. Each species with occurrence in five or more stands was numerically coded. All plot data were then key-punched for computer processing.

3. Computer printouts of synthesis tables (Mueller-Dombois and Ellenberg 1974) were made from the data available for our area. Some data from similar studies in adjacent areas were also included in initial analyses and later omitted. Separate tables were prepared for each series (all stands having the same climax-dominant tree species). Stands were arranged according to general similarities of vegetal composition and relationships to existing classifications from adjacent areas. The synthesis tables were studied in detail and those species that showed consistent differential distributions were underlined. Synthesis tables were rearranged several times to group those stands most similar in overall composition and to segregate groups with consistent differences. The final arrangement provided the formal basis for deriving series, habitat types, and phases.

4. Characteristic vegetational parameters for the plant associations were then identified and briefly described; from this, a parallel key to the habitat types was constructed. This key was then applied to all plot data on hand. The descriptions and key were revised to accommodate individual stand data.

5. Constancy and average cover values were calculated for the important indicator plants following the previous adjustments. A complete presence list was prepared for all vascular plants represented in at least five stands to allow further evaluation of species distributions.

6. The habitat type names were adjusted to compare as directly as possible with those of R. and J. Daubenmire (1968), Pfister (1972a), Cooper (1975), Wirsing and Alexander (1975), Hoffman and Alexander (1976), Henderson and others (1976, 1977 unpubl.), Pfister and others (1977) and Steele and others (1981), and to express the interrelationships of types as clearly as possible. The phase was used to subdivide habitat types based on consistent vegetational differences. In some cases, a phase represents a portion of a habitat type, with some characteristic of an adjacent habitat type; for example, *Abies lasiocarpa/Vaccinium globulare* habitat type, *Vaccinium scoparium* phase. Phases may also distinguish geographic subdivisions of types having very wide distributions; for example, *Pseudotsuga menziesii/Acer glabrum* habitat type, *Pachistima myrsinites* phase.

7. The preliminary classifications (Steele and others 1977, 1979 unpubl.) including descriptions of each type were presented at training sessions in 1977 and 1979 and promptly put into use. Evaluations by the users were solicited, and reported problems sometimes revealed situations that needed more sampling.

8. Data from this later sampling were combined in this report. Pertinent data from all studies were included when developing synthesis tables, redefining types where necessary, rewriting the keys, checking all stands against the classification, and mutually agreeing on the types and phases. About 4 percent of our sample stands did not fit the resulting classification. These stands apparently represent ecotones, vegetational mosaics, unusual seral com-

munities, very dense stands with little undergrowth, or unique associations. It is also possible that some may reflect local habitat types for which we have insufficient data.

9. A map showing the known locations of each habitat type (dots) was prepared using data from all studies within the area and supplemental data from several cooperators who were using the preliminary classification for other field studies (see acknowledgments). As these distribution maps became more complete, the affinities of a habitat type to regional climatic, geologic, or floristic patterns became more evident and helped improve our understanding of each classified unit. Arrows were used on some maps to indicate when a habitat type occurs beyond the study area.

10. A description was prepared for each defined habitat type, including a general discussion of physical environmental features, geographic distribution, key vegetational features, descriptions of phases and basis for their recognition, and general implications for management.

11. This classification can serve as a foundation for developing "site-specific" management implications and future research studies. One of the key management implications developed in conjunction with this study is an appraisal of timber productivity which is included in the discussion section. Understanding the environmental and vegetational features of each habitat type can provide general guidance for many other management questions. Some of the more obvious interrelations applicable to management are noted in the habitat type descriptions and the discussion section.

Taxonomic Considerations

Most plants were identifiable to species, but a few vegetative specimens remain unidentified. Voucher specimens were collected during the course of stand sampling and are deposited in the herbarium of the Intermountain Forest and Range Experiment Station at Boise (BOIS). Taxonomic nomenclature follows Hitchcock and Cronquist (1973). Species not covered in that treatment follow Harrington (1954).

Special attention is needed to distinguish *Pinus albicaulis* from *P. flexilis*. Cones of *P. albicaulis* are purplish and disintegrate on the tree, leaving mainly detached scales on the ground. Cones of *P. flexilis* turn from green to brown and remain intact on the ground for a few years. *P. flexilis* occurs throughout most of the study area at lower elevations of the forest zone and extends upward on the warmer exposed aspects. *P. albicaulis* is more common in the northern half of the study area and becomes scarce on the Caribou National Forest. It occurs mainly at upper elevations of the forest zone and extends downward on the cooler aspects. Occasionally, as in the Wind River Mountains, the two species overlap in their elevational distributions, but even here much of the population is separated by specific site conditions. (See descriptions of *PIAL* and *PIFL* series.)

It is sometimes difficult to distinguish *Picea engelmannii* from *P. glauca*. Ovuliferous cone size and cone scale morphology offer the most reliable and accessible characters for species delineation and provide an index to the degree of hybridization. Cones of *P. engelmannii* are generally 4 to 5 (occasionally 6) cm (1.6 to 2 (occasionally 2.4) inches) long. Their orbicular to oval scales are broadest near the mid-point and have a wavy irregular margin along the tip. Cones of *P. glauca* are 2.5 to 3.5 (occasionally 6) cm (1 to 1.4 (occasionally 2.4) inches) long. Their scales are broadest distally beyond the mid-point and have nonwavy entire margins. The single most easily obtained discriminating character is the absolute length of free scale (distance from the tip of the seed wing imprint to the scale tip); *P. glauca* has a free scale length of 2.8 mm (0.110 inches) or less, whereas that of *P. engelmannii* is 2.9 mm (0.114 inches) or greater (Daubenmire 1974). It is often stated that 1-year-old twigs of *P. engelmannii* are finely pubescent whereas those of *P. glauca* are not. This characteristic is not consistent with the above description of cone characteristics for a number of populations in the study area. Twig pubescence as an important diagnostic character should be discounted.

In Montana, Pfister and others (1977) found that most populations of *Picea* contain hybrids of *P. engelmannii x P. glauca*. The degree of hybridization varies from almost none to a rather even mix, but *P. engelmannii* traits tend to predominate. In the Bighorn Mountains east of the study area, these hybrid conditions are strongly expressed but the *P. glauca* traits gradually decrease toward the north and west, and south to about the Wind River Range. It is in this area of hybridization that *Picea* appears on notably dry habitats and *Picea* habitat types are most extensive.

Picea pungens occurs in several parts of the study area but shows no evidence of hybridization with either *P. glauca* or *P. engelmannii* (Daubenmire 1972). *P. pungens* is rather easily distinguished from trees approaching *P. glauca* by its greater cone length, which ranges from 4 to 10 cm (1.6 to 3.9 inches), with a usually cited length of at least 6.0 cm (2.4 inches), and by its truncate-diamond shaped cone scale, the widest point of which is much below the middle. Separation of *P. pungens* from *P. engelmannii* is best accomplished by comparing shape of cone scales, as described above, and length of free scale. The free scale of *P. pungens* extends more than 7.3 mm (0.29 inches) beyond the seed wing imprint, whereas the imprint tip to scale tip distance in *P. engelmannii* is less than 7.3 mm (0.29 inches). With age, *P. pungens* also develops a fissured bark whereas the bark of even large *P. engelmannii* remains scaly. *P. pungens* occurs in minor amounts on the flood plains and river bottomlands in the Snake River drainage from about Palisades Dam in Idaho upstream into Wyoming and in the Green River drainage of Wyoming. Individual trees may also be found on slopes well above the bottomlands, but the extensive populations mapped in Idaho by Little (1971) were not encountered.

Stickney (1972 unpubl.) found that essentially all of the *Vaccinium globulare* and *V. membranaceum* material col-

lected in Montana would best be labeled *V. globulare*. Using shape of flowers as the diagnostic feature, it appears that most flowering material observed in central Idaho also best conforms to *V. globulare* (Steele and others 1981). Only a small amount of flowering material was found in the study area, but this also fits *V. globulare*. Thus for the sake of uniformity we have chosen *V. globulare* as the epithet for the entire complex within the study area.

Symphoricarpos albus and *S. oreophilus* are sometimes confused unless certain features are noted. The 1- to 3-year-old stems of *S. albus* when sliced obliquely with a sharp knife show a small but definite hole running through the pith; the shrub is rhizomatous, creating continuous colonies. Stems of *S. oreophilus* have a solid pith and the shrub is nonrhizomatous causing it to grow as individual clumps. In the study area, *S. albus* grows mostly on stream terraces, moist areas, and fine-textured soils, whereas *S. oreophilus* is widespread and often abundant on ridges and dry rocky slopes.

Distinguishing *Thalictrum occidentale* from *T. fendleri* is practically impossible without mature fruits; Hitchcock and Cronquist (1973) should be consulted for these identifications. Generally, mature fruits of *T. occidentale* are reflexed and elliptic. Those of *T. fendleri*, are somewhat erect and obliquely obovate-elliptic to narrowly elliptic. Most *Thalictrum* in the study area appears to be *T. fendleri*, with *T. occidentale* occurring mainly on moist sites north of the latitude of Alpine, Wyo.

Osmorhiza chilensis and *O. depauperata* are also difficult to separate without fruits. In this case, however, the two species often occur on the same site and within the study area their ecologies appear similar enough to be grouped as one. Mature fruits of *O. chilensis* are concavely narrowed toward the tip while those of *O. depauperata* are strongly convex.

Distinguishing *Arnica cordifolia* from *A. latifolia* can be confusing; flowering plants are usually needed for positive identification. The leaves on flowering stems of *A. latifolia* are largest toward the middle and are short-petioled to sessile, whereas those of *A. cordifolia* are largest near the base and are distinctly petiolate. *A. latifolia* is restricted to relatively moist sites; *A. cordifolia* occurs on many dry forest sites.

Physocarpus malvaceus and *P. monogynus* both occur in the study area, but apparently their ranges do not overlap. *P. malvaceus* occurs in the Snake, Bear River, and Yellowstone drainages, while *P. monogynus* occupies only small areas in the Wind River Canyon. These species appear very similar, especially beneath a tree canopy. The key characteristic is that the stigmas of *P. malvaceus* are erect, whereas those of *P. monogynus* diverge strongly along with the tips of the carpels. Along the eastern foothills of the Absaroka Range, some populations of *Physocarpus* appear as intergrades between the two species but were treated herein as *P. malvaceus*.

SYNECOLOGIC PERSPECTIVE AND TERMINOLOGY

The Habitat Type Concept

A habitat type is all the land capable of producing similar plant communities at climax (Daubenmire 1968). Because it is the end result of plant succession, the climax plant community reflects the most meaningful integration of environmental factors affecting vegetation. Each habitat type represents a relatively narrow segment of environmental variation and is delineated by a certain potential for vegetational development. Although one habitat type may support a variety of disturbance-induced or seral plant communities, the ultimate product of vegetational succession anywhere within one habitat type will be similar climax communities. Thus, the habitat type system is a method of site classification that uses the plant community as an indicator of integrated environmental factors as they affect species reproduction and plant community development.

The climax community type provides a logical name for the habitat type, for example *Pseudotsuga menziesii/ Calamagrostis rubescens*. The first part of this name is based on the climax tree species, usually the most shade-tolerant tree species adapted to the site. This level of stratification is called the series and encompasses all habitat types having the same dominant tree at climax. The second part of the name is based on the dominant or characteristic species in the undergrowth of the climax community.

Use of climax community types to name habitat types does not imply an abundance of climax vegetation in the present landscape. Actually, most vegetation in the landscape reflects some form of disturbance and represents various stages of succession towards climax. Habitat type names do not imply that we should manage for climax vegetation. In most cases, seral timber species are considered the most productive. Furthermore, this method does not require the presence of a climax stand to identify the habitat type. It can be identified during most stages of succession by comparing the relative reproductive success of the tree species present with known successional trends and by inspecting the existing undergrowth vegetation. During succession, the undergrowth seems to progress toward climax more rapidly than the tree layer and composition of the undergrowth may become relatively stable soon after the coniferous canopy closes. For stands in very early successional stages, the habitat type can often be identified by comparison with adjacent mature stands having similar topographic and edaphic features.

Certain analogies with the systematic taxonomy of plants and the ecology of plant species can help convey ideas on the taxonomic and ecologic nature of habitat types. Habitat types (like plant species) have variable characteristics that complicate identification of individual stands (like individual plants). Closely related habitat types (like

closely related species) share many traits and are distinguished by relatively few features. Individual stands within a habitat type (like individual plants within a species) may display some modal characteristics and some traits transitional to other habitat types (other species). "Hybrid stands" (like hybrid plants) are not uncommon, especially along transitions between major climatic regimes, and vegetation or physiographic provinces.

Habitat types (like plant species) have geographic distributions and geographic variation that follow regional patterns of floristics, climate, and topography. As in plant species, one may also talk of endemic and disjunct distributions among habitat types. Widespread habitat types (like widespread plant species) often occupy a variety of site conditions near the center of their distribution, but at their extremes they are generally restricted to more specific substrates and topographic positions. Thus, habitat types vary geographically in the amount of area each one occupies but their relative position along environmental gradients remains the same, even though additions and deletions of habitat types may change the actual sequence.

In developing habitat type classification, potentially important differential species (indicator species) are evaluated in conjunction with stand characteristics, geographic distribution, amplitudes, and zonal sequences of the types. The significance of habitat type indicators is not the species per se but rather their ability to dominate, or survive competition, at climax in a segment of their environment. Therefore, selecting differential species to develop and define the classification system requires consideration of their (1) opportunity to dominate and (2) competitive abilities.

The opportunity for a species to dominate at climax is determined by its relative ecologic amplitude. In order to have this opportunity, a species must have enough amplitude to extend beyond the environmental limits of its superior competitors. Generally, this results in a species becoming the climax dominant on sites where environment is not optimum for the growth of that species. These sites, however, provide the most favorable competitive conditions. In general, a species has the greatest opportunity to become a climax dominant between its own environmental limits and the environmental limits of its superior competitors. Therefore, where climax dominance denotes a relatively small segment of a species total ecologic amplitude, that species holds high potential as a habitat type indicator. On some sites, differential species are selected that do not attain climax dominance. These species have relatively narrow ecologic amplitudes and the ability to survive in the face of competition near certain extremes of their environment. In these plant communities, species having the least relative amplitude tend to have the greatest potential as habitat type indicators.

The competitive ability of forest species to dominate at climax depends on their reproduction methods, growth habit, shade tolerance, and possibly allelopathic resistance or influence. Most coniferous tree species reproduce primarily by seed. If seed production and seedbed conditions are adequate, superior competition is expressed through relative reproductive rates and shade tolerance. Many species in forest undergrowths, and a few coniferous trees, can reproduce vegetatively and thereby achieve an additional competitive advantage. During later successional stages, vegetative reproduction is often a primary factor in maintaining a competitive position. As a result, most species in the forest undergrowth that are selected as habitat type indicators can dominate through vegetative reproduction.

In any classification system, intergrades exist and in the case of habitat types, one must work between extreme concepts of either (1) narrowly defined types with resultant broad ecotones, or (2) broadly defined types with narrow ecotones. One must also choose between a simple system of a few broad types versus numerous narrowly defined types. Our written descriptions of types portray modal conditions and emphasize the central characteristics of the type. On the other hand, the key is written in specific terms that narrow the ecotones for field identification. We have tried to achieve a manageable balance among numbers of classified units, natural variation, and application of the taxonomy to field conditions. Some variation is recognized within all habitat types; where possible, phases are defined to reflect major within-type variation.

Because the relative amounts of types vary from one geographic area to another, one must exercise judgment when identifying ecotones. For instance, a type may occupy a broad area between two other types in one geographic area, but may be recognizable only as a narrow ecotonal situation in other geographic areas. Scale of mapping and type of management action will influence how these transitional areas are interpreted and displayed. Transitional areas (ecotones) and "hybrid stands" may complicate matters, but can still be mapped as intergrades, referenced to adjacent types, and managed accordingly.

In discussing the relationship of a habitat type to certain environmental features, we have followed the general polyclimax concept of Tansley (1935). Thus, a **climatic climax** is found on deep loamy soils of gently undulating relief; an **edaphic climax** develops on the other soils and types of relief; and a **topographic climax** reflects compensating effects of aspect, or different microclimatic effect. The **topoedaphic climax** is a convenient way to designate deviation from a climatic climax due to combined effects of **edaphic** and **topographic** features. Some habitat types are exclusively one type of climax, but most can be found in any category, depending on the interaction of specific environmental features. In steep mountainous terrain, climatic climax sites are generally scarce. Most stands observed are influenced strongly by topographic features such as aspect and slope or by edaphic features such as loess or volcanic ash deposits.

The habitat type classification is useful to forest management in several ways. It provides a permanent and ecologically based system of land stratification in terms of vegetational potential (Daubenmire 1976). It also provides a classification system for near climax forest communities. Each habitat type encompasses a certain amount of environmental variation, but the variation within a particular habitat type is generally less than between types. Thus, successional trends should be predictable for each habitat type and responses to management treatments should be similar on most lands within the same type or phase.

Habitat Type Versus Continuum Philosophy

For many years, ecologists who studied plant communities debated the interpretation of plant community organization. Although several philosophies developed, debate often centered on two of them: (1) advocates of typal communities argued that distinct vegetational types develop at climax and reappear across the landscape wherever environmental conditions are similar (Daubenmire 1966); (2) continuum advocates argued that even at climax, vegetation, like environment, varies continuously over the landscape (Cottam and McIntosh 1966; Vogl 1966). Some who advocated the typal communities philosophy related habitat type classifications to the relatively "clear cut" taxonomic classification of the plant kingdom. Some continuum advocates regarded habitat type classifications as an attempt to categorize arbitrary intervals along a complex vegetational continuum. Interest in this debate is now declining as shown by Collier and others (1973), who present these contrasting philosophies and advocate an intermediate viewpoint.

Although this debate may still be of some academic interest, it need not preoccupy natural resource managers and field biologists who need a logical, ecologically based environmental classification with which to work. We acknowledge that continua may exist in the landscape; nevertheless, our objective is to develop a logical site classification based on the natural patterns of potential climax vegetation. Local conditions that deviate from this classification can still be described in terms of how they differ from the typal descriptions presented herein.

THE PHYSICAL SETTING

Physiography And Geology

The study area includes portions of five physiographic provinces (Fenneman 1931) and encompasses a multitude of land forms generated by many different geomorphic processes. The great majority of the area lies within the Middle Rocky Mountain Province, which includes three geologically distinct groups of mountain ranges.

The western mountain group, known collectively as the Wyommide Ranges, includes the Gros Ventre, Snake River, Big Hole, Hoback, Salt River, Wyoming, and Teton Ranges; all are characterized by conspicuous thrust faulting and according to Fenneman (1931) would be considered part of the Basin and Range Province were it not for the intervening expanse of the Snake River Plain.

Running north-south along the eastern margin of the study area, the Absaroka Range, Washakie Mountains, and the westernmost projection of the Owl Creek Range represent eroded extrusive volcanic rock, composed chiefly of basic andesitic breccia and basalt (Thornbury 1965). Immediately to the west of the Absaroka Range, flows of acidic extrusive rock, rhyolite and rhyolitic tuff, blanket the plateaus of Yellowstone National Park. Relatively infertile coarse alluvium from these plateaus has been deposited in the West Yellowstone Basin.

The third and easternmost group, the Wind River and eastern portion of the Owl Creek Range, was generated by domal uplifts with cores of acidic intrusive igneous (granitics) or metamorphic rocks.

The west slope of the Absaroka Range, perhaps the most extensively forested upland in the study area, is blanketed by stands composed mainly of *Pinus contorta*, *Pseudotsuga menziesii*, *Picea engelmannii*, and *Abies lasiocarpa*; *Pinus albicaulis* stands are extensive at the highest forested elevations. In contrast, the Yellowstone Plateau area is forested with uniform expanses of *Pinus contorta* (with scattered to dense *P. albicaulis*) and occasional stands of *Abies* and *Picea*, usually on sites protected from fire. Similar expansive and persistent *P. contorta* stands on acidic rocks have been described for the West Yellowstone Basin in Montana (Cooper 1975; Pfister and others 1977), the Bighorn Mountains (Despain 1973), and Wind River Range (Reed 1976) in Wyoming, and the Front Range in Colorado (Moir 1969).

To the south, the fault block Teton Range, rising to numerous 3 660 m (12,000 feet) peaks, exposes on its east face the largest expanse of intrusive igneous rocks in the study area, exclusive of the Wind River Range. The less steep western slope is composed primarily of sedimentaries; both slopes appear equally and densely forested by seral stands of *Pseudotsuga* and *Pinus contorta*. Areas free of fire for several hundred years support near climax stands of *Abies lasiocarpa* and *Picea*. Orographically stimulated precipitation in the vicinity of the Tetons may be the highest of any location within the study area. A continued high precipitation since Pleistocene may explain why the Tetons vicinity has served as a refugium for such disjunct species as *Xerophyllum tenax*, *Ledum glandulosum*, *Menziesia ferruginia*, and *Luzula hitchcockii* which are more typical of the Northern Rocky Mountains, where a maritime influence extends far inland.

Down-faulted Jackson Hole is mantled for most of its length on the western edge with glacial till of several origins; most of the till is forested with *Pinus contorta* and *Populus tremuloides*. The associated glacial outwash plains support primarily shrub-steppe (*Artemisia* spp. and *Purshia tridentata* dominated) communities (Oswald 1966; Sabinski and Knight 1978).

The extensive Gros Ventre and Hoback Ranges (to 3 350 m, 11,000 feet) are less dissected and not as high as the Teton Range and are less forested, with lower slope stands more strongly confined to northern aspects. To the south and east, in the Wind River, Owl Creek, and southern Absaroka Ranges, the landscape appears much drier, and the lower tree-line is elevated by some 150 to 300 m (500 to 1,000 feet). The forests of these ranges relate strongly to parent material. Expansive *Pinus contorta* forests occupy the central granodiorite core of the Wind River Range; some of these stands appear to be climax (Reed 1976). The eastern slope of the Wind River Range, exhibiting one of the most extensive calcareous substrates within the study area, is strongly dominated by *Pseudotsuga* and *Picea* habitat types; *P. contorta* is notably absent. Earle Layser (consultant, Pers. Comm.) has also noted certain forest relationships to limestone in the Gros Ventre Mountains. Very similar patterns of tree response to substrate have been reported by Despain (1973) for the Bighorn Mountains in Wyoming and by Goldin and Nimlos (1977) for the Garnet Mountains in Montana.

The sediment-filled Island Park Basin also supports extensive stands of *Pinus contorta* but their mesic undergrowths suggest that *P. contorta* is largely seral. This basin is bordered on the north by the Centennial Range, which is an oddity in its east-west orientation, and is part of the Northern Rocky Mountain Province. The Centennials support *Pseudotsuga* and *Abies* habitat types on volcanic and sedimentary substrates. At its eastern end, the Centennial Range is joined by a southward trending geosyncline of the Madison Range (Thornbury 1965). In this portion of the Madison Range parent materials are diverse and convoluted. The western face of this range supports rather dry habitat types; *Populus tremuloides* is well represented as both a seral and perhaps a climax species. Its abundance tends to increase from the southern arm of the Madison Range eastward to the Yellowstone Plateau and southward to the Bear River Range on the Utah border.

From the Teton, Gros Ventre, and Hoback Ranges to the Bear River Range are a complex of mountains characterized by extensive overthrust faulting which has convoluted their sedimentary origin. Here few summits exceed 2 740 m (9,000 feet) except for sections of the Wyoming and Salt River Ranges. The *Pseudotsuga* and *Abies* series are well developed on these sedimentaries. Minor ranges west of the Bear River Range lie in the Basin and Range and Columbia Plateau provinces and protrude above a layer of late tertiary basaltic lavas mantled with Pleistocene alluvium. Some of these mountains are volcanic erosional remnants while others, such as the Albion Range contain uplifted sedimentaries. These mountains are only partially forested by the *Abies* and *Pseudotsuga* series.

Climate

Baker (1944) has presented climatic descriptions for the mountainous areas of the West. Although the study area encounters six of his climatic regions, the bulk of the area lies within his western Wyoming and central Wyoming designations (other regions include southwestern Montana, central Idaho, Utah, and basin and range regions). Baker (1944) states that the precipitation regime in western Wyoming is more evenly distributed month to month than in any other part of the West. To the east in the central Wyoming region, precipitation is markedly less, with a notable peak in May typical of a continental regime. Weather data (appendix D-2) from the West Yellowstone, Snake River, and Moose stations in western Wyoming versus stations to the east such as Pinedale, Dubois, Louis Lake, and most notably Willow Park in the Bighorn Range, demonstrate these contrasting regimes. Baker (1944) stated that these two different precipitation regimes were separated by the crest of the Wind River Range. More recent records than were available to Baker, including storage gage stations, indicate that the continental regime encompasses the entire Wind River Range rather than just the eastern half.

The continental effect is also evident across the northern lower elevations of Yellowstone Park. To the west and south and at upper elevations to the east, however, this effect is progressively reduced by the overriding Pacific maritime influence. The transition from low total precipitation of the central Wyoming regime to higher totals of the western Wyoming regime occurs roughly along a line slightly east of the crest of the Absaroka Range from about Cooke City, Mont., to Togwotee Pass and south to Bondurant, Wyo. Some indicator species with high coverages to the west rarely appear east of this line in the study area, for example, *Calamagrostis rubescens, Carex geyeri, Symphoricarpos albus, Spiraea betulifolia, Vaccinium globulare, Lonicera utahensis, Linnaea borealis, Sorbus scopulina, Goodyera oblongifolia*, and *Galium triflorum*.

South of Bondurant, records of the Border, Wyo., station (fig. 2) and other stations west of the Salt River Mountains show a precipitation pattern similar to that of the Jackson Hole area. A lack of sufficient stations east of the Salt River Range precludes any conclusions as to precipitation patterns in this area. Nevertheless, records of nearby stations (Border and Pinedale, Wyo.), and vegetational patterns indicate a transition from a relatively moist climate in the west to a dry continental climate in the east.

Though Baker (1944) recognized a southwestern Montana region, which includes northern Yellowstone Park, examination of his precipitation and temperature data indicates that the climate is quite similar to the central Wyoming regime; Baker's separation of the two regimes

was probably based on differences that would be expected when two areas are separated by a large mountain mass such as the northern Absaroka and Beartooth Ranges. Vegetational patterns of the two areas are similar and reflect a continental climate.

The extreme northwestern portion of the study area lies within the eastern half of Baker's (1944) central Idaho region. Although precipitation patterns from weather stations in that area (Spencer Ranger Station and Kilgore) correspond to that of Baker, they do not correspond to the typical pattern of eastern central Idaho, which reflects a much stronger continental climate than Baker's (1944) pattern of central Idaho suggests. In fact, precipitation and vegetational patterns of the Spencer R.S.-Kilgore forested area relate more closely to immediate areas of the western Wyoming regime than the actual central Idaho regime (eastern half).

The southwestern portion of the study area lies mainly within Baker's (1944) basin and range regime and includes a small projection of his Utah region. Although no stations have been maintained in the mountains, nearby valley stations, Oakley and Malta, indicate that May and June are the wettest months and only a slight moisture peak occurs in the winter months. This pattern probably typifies the northern basin and range region although Baker gives no data for comparison.

Several classic climatic effects are represented by stations within the study area. Island Park Dam, at 1 920 m (6,300 feet) in elevation, reports more total precipitation than Lake Yellowstone, which lies 488 m (1,600 feet) higher on the Yellowstone Plateau to the east. The higher precipitation at Island Park Dam reflects the "approach effect" generated by air masses being forced upward as they encounter the first mountainous area after traversing the Snake River Plains. The southwestern corner of Yellowstone Park is generally considered to have the greatest snow accumulation in the Park and data from the weather station closest to this area, Snake River R. S., supports this observation. This portion of the Park, like the Snake, Big Hole, and Caribou Ranges are the first large mountains to intercept storm systems traversing the Snake River Plains. Consequently, these mountains support some relatively moist upland habitat types.

West Yellowstone at 2 030 m (6,667 feet) is a colder station than would be expected at that elevation. This station lies in a large basin that impounds the cold air flowing off surrounding uplands. This "frost pocket effect" combined with sandy alluvial substrates results in a distinct *Pinus contorta/Purshia tridentata* association (Pfister and others 1977).

The Valley 6W station lies east of the Continental Divide in the Absaroka Range and registers the greatest precipitation of any station in the study area. This precipitation may be augmented by the "canyon effect," which collects precipitation generated by adjacent mountain ridges. Valley 6W, a moist subalpine station, may be contrasted with the dry subalpine climate of the St. Lawrence and Mosquitoe Park Stations in the Wind River Range. The Wind River Range, with its conspicuously low amounts of winter precipitation, may represent the "rain-shadow effect" created by high mountain ranges to the west and north as well as a moderate continental regime.

SUCCESSIONAL STATUS OF EASTERN IDAHO-WESTERN WYOMING FORESTS

Fire History

Data and observations from the study area support the general conclusion of Wellner (1970) that fire has burned over most all forest land in the northern Rocky Mountains at one time or another. In northwestern Wyoming, these were mostly small fires that crept sporadically through the forest, consuming litter and tree seedlings but seldom killing the larger trees (Loope and Gruell 1973). Prior to fire suppression, this type of fire probably occurred about every 20-25 years in northern Yellowstone Park (Houston 1973) and about every 50-100 years in the Jackson Hole area (Loope and Gruell 1973). To the south and east of these areas it appears that fire frequency may have been even less.

Immediately after burning, stands are relatively fire resistant, but as plant succession advances, the susceptibility to large, devastating fires increases. The infrequent combination of heavy, high fuel loads, extremely dry conditions, several ignition sources, and high winds produced conflagrations in the Jackson Hole area in the 1840's, 1870's and 1880's (Loope and Gruell 1973). Houston (1973) estimates that 8 to 10 large, widespread fires have occurred in northern Yellowstone Park in the past 300-400 years.

In recent years, organized fire suppression has substantially reduced fire frequency and has allowed plant succession to achieve fuel conditions more prone to intense wildfire. These fuel buildups tend to occur more rapidly in the more productive habitat types (appendix E-2). Many of the less productive types such as in the *Pinus flexilis* and *P. albicaulis* series can still support only creeping groundfires even after several hundred years of uninterrupted succession. Gruell (1980) illustrates various forest successions and the consequent fuel buildups in part of the study area.

Grazing History

Early, unregulated cattle grazing and later sheep grazing have substantially affected portions of the study area. Cattle originally depleted much of the available forage near lower elevations of the forested zone. In general, these effects increased from north to south. In the north, range depletion was estimated at 0 to 25 percent of virgin condition while some areas in the south were estimated at more than 75 percent (McArdle and others 1936). Local exceptions occur in the vicinity of livestock driveways, pioneer travel routes, and early settlements. In all areas, the most serious depletion was on private and public do-

main lands, but wherever the forest becomes interrupted by meadows and sage-grass communities, it is more vulnerable to livestock damage. The animals use much of the forest that borders rangeland for bedding and shelter and severely trample forest undergrowths. Consequently, old growth stands in these areas rarely have undergrowth development indicative of stand age.

By the turn of the century, the early cattle boom had ended, but as cattle numbers began adjusting to range capacity, sheep numbers increased dramatically. By 1903, Idaho had 2.6 million sheep and by 1909, Wyoming had 6 million (Stewart 1936). Ideal summer range in the study area no doubt attracted a large percentage of these animals at least part of the year. Because there were no grazing allotments, various sheep herds competed for the forage by racing to summer ranges, using as much forage as possible, and leaving the site unfit for other herds (Stewart 1936). Consequently, range depletion by sheep occurred from lower elevations to ridges and mountain meadows at upper elevations.

Today, smaller bands of sheep still graze the upper ridges and meadows in much of the study area and cattle graze in parts of the mid- and lower elevation forests. Although the widespread grazing abuse of the early 1900's has ended, localized abuse still occurs wherever animals congregate.

As with cattle, the adverse effects of sheep in the study area increase from north to south. Although some fragile, high elevation sites along the Montana border are still heavily grazed, the most serious depletion exists near the Utah border. Here, some forested areas contain very few undergrowth species and the adjacent openings contain mostly bare soil or *Rudbeckia*, and other species indicative of severe disturbance.

In most river valleys of the study area, reduction of forage by livestock, agriculture, and settlements conflicts with winter forage demands of big game animals. In some areas, this in turn causes severe big game use of adjacent forests. Most notable is in the valleys of the upper Snake River drainage system, where big game animals are fed hay and alfalfa pellets in winter to alleviate the conflicts created by man and his animals. Here, some coniferous forest communities have been severely altered by wintering big game and some aspen communities have been decimated by a combination of big game, insects, and disease (Krebill 1972). On some big game wintering grounds, livestock use has been curtailed on the Federal lands to help reduce this conflict.

Logging History

Early logging activities concentrated in the lower elevation forests most accessible from towns, homesteads, mining developments, and major rivers. Usually only high quality timber was taken and the stands were left in a degraded condition. In some areas, railroad construction created an early demand for timber. The demand for railroad ties centered on *Pseudotsuga* and *Pinus contorta* of sizes which could be easily hacked into ties. Such "tie-hack" operations again focused on low-elevation forests, often a considerable distance from any settlement. Tie cutters would eliminate certain size classes of timber and leave behind the large, unwieldy and the small, unprofitable trees. Effects of early "tie hacking" are still visible in certain stands.

Early commercial lumbering also concentrated on the most accessible forests but gradually gained access to more remote stands of valuable timber. Now, access to uncut stands is sought continually but in some places the combination of steep terrain and low quality timber has deterred commercial interests. In other areas, large-scale timber harvesting continues and examples of certain undisturbed forest communities will soon be very rare. Two national parks and several wilderness areas have preserved many representative plant communities. Most of these preserved communities, however, represent only the higher elevations and are concentrated in the northeastern quarter of the study area. Examples of old-growth forest in the remainder of the study area are rapidly disappearing.

THE HABITAT TYPE CLASSIFICATION

Some 50 forest habitat types have been defined within the study area. This seemingly large number reflects the environmental diversity encountered. The total classification is listed in table 1 for easy reference and includes eight incidental habitat types. The term "habitat type" is mentioned so often that the abbreviation "h.t." ("h.t.'s" plural) is used to save space. Frequent use of h.t. names in the text also create a need for abbreviations. We have used the first two letters of the genus and the first two letters of the species of the two plants involved as the taxonomic abbreviation of each h.t. Scientific names of h.t.'s and their abbreviations are listed in table 1. Scientific, abbreviated, and common names of indicator species are listed in the h.t. field form (appendix F). Common names are not used in the text because variation in their local usage may cause confusion. Initially, these abbreviations may seem strange, but professional foresters and biologists are accepting them as a convenient substitute for common names.

The classification is presented in the following order:

1. Key to the habitat types.— The first step in correct identification of the habitat type is becoming familiar with the instructions for use of the key. Next comes identification of the potential climax series, followed by identification of the habitat type and then the phase.

2. Series description.—Many habitat type characteristics are summarized at the series level, rather than repeating general similarities in vegetation and habitat characteristics for each habitat type description.

3. Habitat type description.—This information summarizes geographic range, vegetation, phases, and general management implications.

Table 1.—Eastern Idaho-western Wyoming forest habitat types and phases and assigned ADP codes

ADP Code[1]	Abbreviation	Habitat Types and Phases: Scientific name	Common name
000		***PINUS FLEXILIS* SERIES**	
080	PIFL/HEKI h.t.	*Pinus flexilis/Hesperochloa kingii* h.t.	limber pine/spike fescue
050	PIFL/FEID h.t.	*Pinus flexilis/Festuca idahoensis* h.t.	limber pine/Idaho fescue
051	-FEID phase	-*Festuca idahoensis* phase	-Idaho fescue phase
060	PIFL/CELE h.t.	*Pinus flexilis/Cercocarpus ledifolius* h.t.	limber pine/curl-leaf mountain-mahogany
070	PIFL/JUCO h.t.	*Pinus flexilis/Juniperus communis* h.t.	limber pine/common juniper
200		***PSEUDOTSUGA MENZIESII* SERIES**	
220	PSME/FEID h.t.	*Pseudotsuga menziesii/Festuca idahoensis* h.t.[2]	Douglas-fir/Idaho fescue
221	-FEID phase	-*Festuca idahoensis* phase[2]	-Idaho fescue phase
380	PSME/SYOR h.t.	*Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t.	Douglas-fir/mountain snowberry
370	PSME/ARCO h.t.	*Pseudotsuga menziesii/Arnica cordifolia* h.t.	Douglas-fir/heartleaf arnica
371	-ARCO phase	-*Arnica cordifolia* phase	-heartleaf arnica phase
372	-ASMI phase	-*Astragalus miser* phase	-weedy milkvetch phase
385	PSME/CELE h.t.	*Pseudotsuga menziesii/Cercocarpus ledifolius* h.t.	Douglas-fir/curl-leaf mountain-mahogany
360	PSME/JUCO h.t.	*Pseudotsuga menziesii/Juniperus communis* h.t.	Douglas-fir/common juniper
395	PSME/BERE h.t.	*Pseudotsuga menziesii/Berberis repens* h.t.	Douglas-fir/Oregon grape
397	-SYOR phase	-*Symphoricarpos oreophilus* phase	-mountain snowberry phase
399	-JUCO phase	-*Juniperus communis* phase	-common juniper phase
398	-CAGE phase	-*Carex geyeri* phase[2]	-elk sedge phase
396	-BERE phase	-*Berberis repens* phase	-Oregon grape phase
320	PSME/CARU h.t.	*Pseudotsuga menziesii/Calamagrostis rubescens* h.t.	Douglas-fir/pinegrass
325	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
323	-CARU phase	-*Calamagrostis rubescens* phase	-pinegrass phase
340	PSME/SPBE h.t.	*Pseudotsuga menziesii/Spiraea betulifolia* h.t.	Douglas-fir/white spirea
343	-CARU phase	-*Calamagrostis rubescens* phase	-pinegrass phase
341	-SPBE phase	-*Spiraea betulifolia* phase	-white spirea phase
375	PSME/OSCH h.t.	*Pseudotsuga menziesii/Osmorhiza chilensis* h.t.	Douglas-fir/mountain sweetroot
310	PSME/SYAL h.t.	*Pseudotsuga menziesii/Symphoricarpos albus* h.t.	Douglas-fir/common snowberry
313	-SYAL phase	-*Symphoricarpos albus* phase	-common snowberry phase
270	PSME/PHMO h.t.	*Pseudotsuga menziesii/Physocarpus monogynus* h.t.[2]	Douglas-fir/mountain ninebark
280	PSME/VAGL h.t.	*Pseudotsuga menziesii/Vaccinium globulare* h.t.	Douglas-fir/blue huckleberry
281	-VAGL phase	-*Vaccinium globulare* phase	-blue huckleberry phase
390	PSME/ACGL h.t.	*Pseudotsuga menziesii/Acer glabrum* h.t.	Douglas-fir/mountain maple
391	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
260	PSME/PHMA h.t.	*Pseudotsuga menziesii/Physocarpus malvaceus* h.t.	Douglas-fir/ninebark
266	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
265	-PSME phase	-*Pseudotsuga menziesii* phase	-Douglas-fir phase
400		***PICEA ENGELMANNII* SERIES**	
493	PIEN/HYRE h.t.	*Picea engelmannii/Hypnum revolutum* h.t.	spruce/hypnum
495	PIEN/ARCO h.t.	*Picea engelmannii/Arnica cordifolia* h.t.	spruce/heartleaf arnica
497	PIEN/RIMO h.t.	*Picea engelmannii/Ribes montigenum* h.t.	spruce/mountain gooseberry
475	PIEN/JUCO h.t.	*Picea engelmannii/Juniperus communis* h.t.	spruce/common juniper
485	PIEN/VASC h.t.	*Picea engelmannii/Vaccinium scoparium* h.t.	spruce/grouse whortleberry
470	PIEN/LIBO h.t.	*Picea engelmannii/Linnaea borealis* h.t.	spruce/twinflower
440	PIEN/GATR h.t.	*Picea engelmannii/Galium triflorum* h.t.	spruce/sweet-scented bedstraw
430	PIEN/PHMA h.t.	*Picea engelmannii/Physocarpus malvaceus* h.t.[2]	spruce/ninebark
490	PIEN/CADI h.t.	*Picea engelmannii/Carex disperma* h.t.	spruce/soft leaved sedge
415	PIEN/CALE h.t.	*Picea engelmannii/Caltha leptosepala* h.t.	spruce/elkslip marsh marigold
410	PIEN/EQAR h.t.	*Picea engelmannii/Equisetum arvensis* h.t.	spruce/common horsetail
600		***ABIES LASIOCARPA* SERIES**	
650	ABLA/CACA h.t.	*Abies lasiocarpa/Calamagrostis canadensis* h.t.	subalpine fir/bluejoint
655	-LEGL phase	-*Ledum glandulosum* phase[2]	-Labrador tea phase
654	-VACA phase	-*Vaccinium caespitosum* phase[2]	-dwarf huckleberry phase
651	-CACA phase	-*Calamagrostis canadensis* phase	-bluejoint phase
635	ABLA/STAM h.t.	*Abies lasiocarpa/Streptopus amplexifolius* h.t.[2]	subalpine fir/twisted stalk
636	-STAM phase	-*Streptopus amplexifolius* phase[2]	-twisted stalk phase
670	ABLA/MEFE h.t.	*Abies lasiocarpa/Menziesia ferruginea* h.t.[2]	subalpine fir/menziesia
671	-MEFE phase	-*Menziesia ferruginea* phase[2]	-menziesia phase
601	ABLA/ACRU h.t.	*Abies lasiocarpa/Actaea rubra* h.t.	subalpine fir/baneberry
603	ABLA/PHMA h.t.	*Abies lasiocarpa/Physocarpus malvaceus* h.t.	subalpine fir/ninebark
645	ABLA/ACGL h.t.	*Abies lasiocarpa/Acer glabrum* h.t.	subalpine fir/mountain maple
647	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
660	ABLA/LIBO h.t.	*Abies lasiocarpa/Linnaea borealis* h.t.	subalpine fir/twinflower
663	-VASC phase	-*Vaccinium scoparium* phase	-grouse whortleberry phase
661	-LIBO phase	-*Linnaea borealis* phase	-twinflower phase
690	ABLA/XETE h.t.	*Abies lasiocarpa/Xerophyllum tenax* h.t.[2]	subalpine fir/beargrass
691	-VAGL phase	-*Vaccinium globulare* phase[2]	-blue huckleberry phase
692	-VASC phase	-*Vaccinium scoparium* phase[2]	-grouse whortleberry phase

(con)

Table 1.—(con)

ADP Code[1]	Abbreviation	Habitat Types and Phases: Scientific name	Common name
720	ABLA/VAGL h.t.	*Abies lasiocarpa/Vaccinium globulare* h.t.	subalpine fir/blue huckleberry
721	-VASC phase	-*Vaccinium scoparium* phase	-grouse whortleberry phase
722	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
723	-VAGL phase	-*Vaccinium globulare* phase	-blue huckleberry phase
830	ABLA/LUHI h.t.	*Abies lasiocarpa/Luzula hitchcockii* h.t.[2]	subalpine fir/smooth woodrush
831	-VASC phase	-*Vaccinium scoparium* phase[2]	-grouse whortleberry phase
730	ABLA/VASC h.t.	*Abies lasiocarpa/Vaccinium scoparium* h.t.	subalpine fir/grouse whortleberry
731	-CARU phase	-*Calamagrostis rubescens* phase	-pinegrass phase
734	-PIAL phase	-*Pinus albicaulis* phase	-whitebark pine phase
732	-VASC phase	-*Vaccinium scoparium* phase	-grouse whortleberry phase
701	ABLA/ARLA h.t.	*Abies lasiocarpa/Arnica latifolia* h.t.	subalpine fir/mountain arnica
607	ABLA/SYAL h.t.	*Abies lasiocarpa/Symphoricarpos albus* h.t.	subalpine fir/common snowberry
609	ABLA/THOC h.t.	*Abies lasiocarpa/Thalictrum occidentale* h.t.	subalpine fir/western meadowrue
760	ABLA/OSCH h.t.	*Abies lasiocarpa/Osmorhiza chilensis* h.t.	subalpine fir/mountain sweetroot
761	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
762	-OSCH phase	-*Osmorhiza chilensis* phase	-mountain sweetroot phase
705	ABLA/SPBE h.t.	*Abies lasiocarpa/Spiraea betulifolia* h.t.	subalpine fir/white spirea
750	ABLA/CARU h.t.	*Abies lasiocarpa/Calamagrostis rubescens* h.t.	subalpine fir/pinegrass
752	-PAMY phase	-*Pachistima myrsinites* phase	-pachistima phase
751	-CARU phase	-*Calamagrostis rubescens* phase	-pinegrass phase
703	ABLA/BERE h.t.	*Abies lasiocarpa/Berberis repens* h.t.	subalpine fir/Oregon grape
704	-CAGE phase	-*Carex geyeri* phase[2]	-elk sedge phase
702	-BERE phase	-*Berberis repens* phase	-Oregon grape phase
790	ABLA/CAGE h.t.	*Abies lasiocarpa/Carex geyeri* h.t.[2]	subalpine fir/elk sedge
791	-CAGE phase	-*Carex geyeri* phase[2]	-elk sedge phase
745	ABLA/JUCO h.t.	*Abies lasiocarpa/Juniperus communis* h.t.	subalpine fir/common juniper
810	ABLA/RIMO h.t.	*Abies lasiocarpa/Ribes montigenum* h.t.	subalpine fir/mountain gooseberry
812	-PIAL phase	-*Pinus albicaulis* phase	-whitebark pine phase
811	-RIMO phase	-*Ribes montigenum* phase	-mountain gooseberry phase
707	ABLA/PERA h.t.	*Abies lasiocarpa/Pedicularis racemosa* h.t.	subalpine fir/pedicularis
780	ABLA/ARCO h.t.	*Abies lasiocarpa/Arnica cordifolia* h.t.	subalpine fir/heartleaf arnica
784	-PIEN phase	-*Picea engelmannii* phase	-Engelmann spruce phase
783	-SHCA phase	-*Shepherdia canadensis* phase	-russett buffalo-berry phase
782	-ASMI phase	-*Astragalus miser* phase	-weedy milkvetch phase
781	-ARCO phase	-*Arnica cordifolia* phase	-heartleaf arnica phase
795	ABLA/CARO h.t.	*Abies lasiocarpa/Carex rossii* h.t.	subalpine fir/Ross sedge
870		***PINUS ALBICAULIS* SERIES**	
875	PIAL/VASC h.t.	*Pinus albicaulis/Vaccinium scoparium* h.t.	whitebark pine/grouse whortleberry
880	PIAL/CAGE h.t.	*Pinus albicaulis/Carex geyeri* h.t.	whitebark pine/elk sedge
885	PIAL/JUCO h.t.	*Pinus albicaulis/Juniperus communis* h.t.	whitebark pine/common juniper
886	-SHCA phase	-*Shepherdia canadensis* phase	-russett buffalo-berry phase
887	-JUCO phase	-*Juniperus communis* phase	-common juniper phase
895	PIAL/CARO h.t.	*Pinus albicaulis/Carex rossii* h.t.	whitebark pine/Ross sedge
896	-PICO phase	-*Pinus contorta* phase	-lodgepole pine phase
897	-CARO phase	-*Carex rossii* phase	-Ross sedge phase
891	PIAL/FEID h.t.	*Pinus albicaulis/Festuca idahoensis* h.t.	whitebark pine/Idaho fescue
900		***PINUS CONTORTA* SERIES**	
930	PICO/LIBO c.t.	*Pinus contorta/Linnaea borealis* c.t.[2]	lodgepole pine/twinflower
935	PICO/VAGL c.t.	*Pinus contorta/Vaccinium globulare* c.t.[2]	lodgepole pine/blue huckleberry
940	PICO/VASC c.t.	*Pinus contorta/Vaccinium scoparium* c.t.[2]	lodgepole pine/grouse whortleberry
945	PICO/SPBE c.t.	*Pinus contorta/Spiraea betulifolia* c.t.[2]	lodgepole pine/white spirea
950	PICO/CARU c.t.	*Pinus contorta/Calamagrostis rubescens* c.t.[2]	lodgepole pine/pinegrass
955	PICO/CAGE c.t.	*Pinus contorta/Carex geyeri* c.t.[2]	lodgepole pine/elk sedge
960	PICO/JUCO c.t.	*Pinus contorta/Juniperus communis* c.t.[2]	lodgepole pine/common juniper
975	PICO/SHCA c.t.	*Pinus contorta/Shepherdia canadensis* c.t.[2]	lodgepole pine/russett buffalo-berry
965	PICO/ARCO c.t.	*Pinus contorta/Arnica cordifolia* c.t.[2]	lodgepole pine/heartleaf arnica
970	PICO/CARO c.t.	*Pinus contorta/Carex rossii* c.t.[2]	lodgepole pine/Ross sedge
990		***POPULUS TREMULOIDES* SERIES**	

Total number of habitat types = 58[3]
Total number of habitat types and additional phases = 82[4]
Total number of *Pinus contorta* community types = 10

[1]Automatic data processing codes.
[2]Incidental habitat types or phases, or *Pinus contorta* community types omitted from other charts and tables
[3]Eight of these are incidental to the study area.
[4]Five of the additional phases are incidental to the study area.

Arrangement of habitat types within the keys tends to progress from the wet-moderate (least stressful) to more severe environments. At the lower elevations, progression through the keys leads to increasingly drier types and at upper elevations it leads to increasingly colder types. Occasionally, this order deviates when habitat types from different geographic areas are merged into one key. Once familiar with the key, awareness of this sequence can help the user identify sites that are difficult to key out. The h.t. descriptions are arranged in the order they appear in the key.

Distributions of h.t.'s are illustrated with dot maps and summarized in the first paragraph of each h.t. description. The arrows on some maps indicate occurrence of that h.t. beyond the study area. The density of dots on some maps is a function of sampling intensity and does not always indicate relative abundance of the h.t. Relative abundance of a type is indicated by the terms: incidental, minor, or major. An incidental h.t. or phase rarely occurs in the study area (hence, no dot map) but was included in the key in case it is encountered. A minor h.t. seldom occupies large acreages but may be common in the study area and of major importance to land management. A major h.t. occupies extensive acreages in at least some portion of the study area.

KEY TO SERIES, HABITAT TYPES, AND PHASES.

READ THESE INSTRUCTIONS FIRST!

1. Use this key for stands with a mature tree canopy that are not severely disturbed by grazing, logging, forest fire, etc. (If the stand is severely disturbed or in an early successional stage, the habitat type can best be determined by extrapolating from the nearest mature stand occupying a similar site.)

2. Accurately identify and record canopy coverages for all indicator species (appendix F).

3. Check plot data in the field to verify that the plot is representative of the stand as a whole. If not, take another plot.

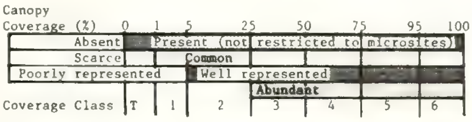
4. Identify the correct potential climax tree species in the SERIES key. (Generally, a tree species is considered reproducing successfully if 10 or more individuals per acre occupy or will occupy the site.)

5. Within the appropriate series, key to HABITAT TYPE and PHASE by following the key literally. Verify your identification by comparing the stand conditions with the written descriptions. (The first phase in the key that fits the stand is the correct one.)

6. Use the definitions diagramed below for canopy coverage terms in the key. If you have difficulty deciding between types, refer to constancy and coverage data (appendix C-1) and the habitat type descriptions.

7. In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, adjust the definitions diagramed below to the next lower coverage class (for example, well represented >1%, common >0%.

8. Remember, the key is NOT the classification! Validate the determination made using the key by checking the written description and appendix C-1.



KEY TO CLIMAX SERIES
(Do Not Proceed Until You Have Read The Instructions)

1. Abies lasiocarpa present and reproducing successfully . . . . ABIES LASIOCARPA SERIES (item F)
1. A. lasiocarpa not the indicated climax 2

2. Picea engelmannii present and reproducing successfully . . . . PICEA ENGELMANNII SERIES (item D)
2. P. engelmannii not the indicated climax 3

3. Pinus flexilis a successfully reproducing dominant in old growth stands; often sharing that status with Pseudotsuga . . . . PINUS FLEXILIS SERIES (item B)
3. P. flexilis absent or clearly seral 4

4. Pseudotsuga menziesii present and reproducing successfully . . . . PSEUDOTSUGA MENZIESII SERIES (item C)
4. P. menziesii not the indicated climax dominant 5

5. Pinus albicaulis present and reproducing successfully . . . . PINUS ALBICAULIS SERIES (item E)
5. P. albicaulis not the indicated successional dominant 6

6. Pinus contorta dominant and reproducing successfully . . . . PINUS CONTORTA SERIES (item A)
6. P. contorta not the indicated successional dominant 7

7. Populus tremuloides the indicated dominant . . . . POPULUS TREMULOIDES SERIES (p.74)
7. P. tremuloides not the indicated dominant. Juniperus osteosperma or Acer grandidentatum dominating the site . . . . Minor forest types (p.75)

A. Key to Pinus contorta Community Types

1. Linnaea borealis common . . . . PINUS CONTORTA/LINNAEA BOREALIS c.t.* (p.72)
1. L. borealis scarce 2

2. Vaccinium globulare well represented . . . . PINUS CONTORTA/VACCINIUM GLOBULARE c.t.* (p.72)
2. V. globulare poorly represented 3

3. Vaccinium scoparium well represented . . . . PINUS CONTORTA/VACCINIUM SCOPARIUM c.t.* (p.72)
3. V. scoparium poorly represented 4

4. Symphoricarpos albus well represented . . . . ABIES LASIOCARPA/SYMPHORICARPOS ALBUS h.t. (p.53)
4. S. albus poorly represented 5

5. Thalictrum occidentale well represented . . . . ABIES LASIOCARPA/THALICTRUM OCCIDENTALE h.t. (p.54)
5. T occidentale poorly represented 6

6. Osmorhiza chilensis or O. depauperata well represented either separately or collectively . . . . ABIES LASIOCARPA/OSMORHIZA CHILENSIS h.t. (p.54)
6. Not as above 7

7. Spiraea betulifolia well represented . . . . PINUS CONTORTA/SPIRAEA BETULIFOLIA c.t.* (p.72) 7
7. S. betulifolia poorly represented 8

8. Calamagrostis rubescens well represented . . . . PINUS CONTORTA/CALAMAGROSTIS RUBESCENS c.t.* (p.72)
8. C. rubescens poorly represented 9

9. Berberis repens common or Pachistima myrsinites well represented . . . . ABIES LASIOCARPA/BERBERIS REPENS h.t. (p.58)
9. B. repens scarce and P. myrsinites poorly represented 10

10. Carex geyeri well represented . . . . PINUS CONTORTA/CAREX GEYERI c.t.* (p.73)
10. C. geyeri poorly represented 11

11. Juniperus communis well represented . . . . PINUS CONTORTA/JUNIPERUS COMMUNIS c.t.* (p.73)
11. J. communis poorly represented 12

12. Shepherdia canadensis well represented . . . . PINUS CONTORTA/SHEPHERDIA CANADENSIS c.t.* (p.73)
12. S. canadensis poorly represented 13

13. Pedicularis racemosa common . . . . ABIES LASIOCARPA/PEDICULARIS RACEMOSA H.T. (p.60)
13. P. racemosa scarce 14

14. Arnica cordifolia or Astragalus miser well represented . . . . PINUS CONTORTA/ARNICA CORDIFOLIA c.t.* (p.73)
14. A. cordifolia and A. miser poorly represented; Carex rossii well represented or the dominant undergrowth species . . . . PINUS CONTORTA/CAREX ROSSII c.t.* (p.73)

B. Key to Pinus flexilis Habitat Types

1. Juniperus communis well represented . . . . PINUS FLEXILIS/JUNIPERUS COMMUNIS h.t. (p.19)
1. J. communis poorly represented 2

2. Cercocarpus ledifolius well represented . . . . PINUS FLEXILIS/CERCOCARPUS LEDIFOLIUS h.t. (p.19)
2. C. ledifolius poorly represented 3

3. Festuca idahoensis well represented . . . . PINUS FLEXILIS/FESTUCA IDAHOENSIS h.t. (p.20)
3. F. idahoensis poorly represented. Hesperochloa kingii (Leucopoa kingii) common . . . . PINUS FLEXILIS/HESPEROCHLOA KINGII h.t. (p.20)

*C.t.s omitted from charts and tables.

C. Key to Pseudotsuga menziesii Habitat Types

1. Physocarpus malvaceus well represented	PSEUDOTSUGA MENZIESII/PHYSOCARPUS MALVACEUS h.t. (p.22)
1a. Pachistima myrsinites usually present, sites south or east of Snake River Plains (fig. 2)	PACHISTIMA MYRSINITES phase (p.23)
1b. P. myrsinites absent, sites north or west of Snake River Plains	PSEUDOTSUGA MENZIESII phase (p.23)
1. P. malvaceus poorly represented	2
2. Acer glabrum or Sorbus scopulina well represented, sites mainly in the Snake and Bear River drainages (fig 2)	PSEUDOTSUGA MENZIESII/ACER GLABRUM h.t. (p.23)
2. A. glabrum and S. scopulina poorly represented, sites not always in Snake and Bear River drainages.	3
3. Vaccinium globulare well represented	PSEUDOTSUGA MENZIESII/VACCINIUM GLOBULARE h.t. (p.24)
3. V. globulare poorly represented	4
4. Physocarpus monogynus well represented	PSEUDOTSUGA MENZIESII/PHYSOCARPUS MONOGYNUS h.t. (p.25)
4. P. monogynus poorly represented	5
5. Symphoricarpos albus well represented	PSEUDOTSUGA MENZIESII/SYMPHORICARPOS ALBUS h.t. (p.25)
5. S. albus poorly represented	6
6. Osmorhiza chilensis or O. depauperata well represented	PSEUDOTSUGA MENZIESII/OSMORHIZA CHILENSIS h.t. (p.26)
6. O. chilensis and O. depauperata poorly represented	7
7. Spiraea betulifolia well represented	PSEUDOTSUGA MENZIESII/SPIRAEA BETULIFOLIA h.t. (p.26)
7a. Calamagrostis rubescens well represented	CALAMAGROSTIS RUBESCENS phase (p.27)
7b. C. rubescens poorly represented	SPIRAEA BETULIFOLIA phase (p.27)
7. S. betulifolia poorly represented	8
8. Calamagrostis rubescens well represented	PSEUDOTSUGA MENZIESII/CALAMAGROSTIS RUBESCENS h.t. (p.28)
8a. Pachistima myrsinites well represented	PACHISTIMA MYRSINITES phase (p.28)
8b. P. myrsinites poorly represented	CALAMAGROSTIS RUBESCENS phase (p.28)
8. C. rubescens poorly represented	9
9. Cercocarpus ledifolius well represented	PSEUDOTSUGA MENZIESII/CERCOCARPUS LEDIFOLIUS h.t. (p.28)
9. C. ledifolius poorly represented	10
10. Berberis repens or Pachistima myrsinites well represented, either singly or collectively	PSEUDOTSUGA MENZIESII/BERBERIS REPENS h.t. (p.30)
10a. Carex geyeri abundant	CAREX GEYERI phase* (p.30)
10b. C. geyeri not abundant; Juniperus communis well represenated	JUNIPERUS COMMUNIS phase (p.30)
10c. Not as above; Symphoricarpos oreophilus abundant, stands never achieving closed canopies	SYMPHORICARPOS OREOPHILUS phase (p.30)
10d. Not as above, stands eventually achieving closed canopies	BERBERIS REPENS phase (p.30)
10. B. repens and P. myrsinites poorly represented	11
11. Juniperus communis well represented	PSEUDOTSUGA MENZIESII/JUNIPERUS COMMUNIS h.t. (p.33)
11. J. communis poorly represented	12
12. Arnica cordifolia well represented or the dominant forb of normally depauperate undergrowths	PSEUDOTSUGA MENZIESII/ARNICA CORDIFOLIA h.t. -ARNICA CORDIFOLIA phase (p.33)
12. A. cordifolia poorly represented	13
13. Symphoricarpos oreophilus, Prunus virginiana, or Ribes cereum, well represented	PSEUDOTSUGA MENZIESII/SYMPHORICARPOS OREOPHILUS h.t. (p.34)
13. S. oreophilus, P. virginiana, and R. cereum poorly represented	14
14. Festuca idahoensis well represented	PSEUDOTSUGA MENZIESII/FESTUCA IDAHOENSIS h.t.* (p.35)
14. F. idahoensis poorly represented	15
15. Hesperochloa kingii (Leucopoa kingii) common	PINUS FLEXILIS/HESPEROCHLOA KINGII h.t. (p.20)
15. H. kingii scarce; Astragalus miser well represented or the dominant forb of normally depauperate undergrowths	PSEUDOTSUGA MENZIESII/ARNICA CORDIFOLIA h.t. -ASTRAGALUS MISER phase (p.33)

D. Key to Picea Engelmannii Habitat Types

1. Equisetum arvense abundant	PICEA ENGELMANNII/EQUISETUM ARVENSIS h.t. (p.36)
1. E. arvense not abundant	2
2. Caltha leptosepala common or Trollius laxus well represented	PICEA ENGELMANNII/CALTHA LEPTOSEPALA h.t. (p.37)
2. C. leptosepala scarce and T. laxus poorly represented	3
3. Carex disperma well represented	PICEA ENGELMANNII/CAREX DISPERMA h.t. (p.38)
3. C. disperma poorly represented	4
4. Physocarpus malvaceus well represented	PICEA ENGELMANNII/PHYSOCARPUS MALVACEUS h.t.* (p.39)
4. P. malvaceus poorly represented	5
5. Galium triflorum, Actaea rubra, or Senecio triangularis common, either individually or collectively	PICEA ENGELMANNII/GALIUM TRIFLORUM h.t. (p.39)
5. Not as above	6
6. Linnaea borealis common	PICEA ENGELMANNII/LINNAEA BOREALIS h.t. (p.39)
6. L. borealis scarce	7
7. Vaccinium scoparium well represented	PICEA ENGELMANNII/VACCINIUM SCOPARIUM h.t. (p.40)
7. V. scoparium poorly represented	8
8. Juniperus communis well represented	PICEA ENGELMANNII/JUNIPERUS COMMUNIS h.t. (p.41)
8. J. communis poorly represented	9
9. Ribes montigenum well represented or the dominant plant of normally depauperate undergrowths	PICEA ENGELMANNII/RIBES MONTIGENUM h.t. (p.41)
9. Not as above	10
10. Arnica cordifolia well represented	PICEA ENGELMANNII/ARNICA CORDIFOLIA h.t. (p.42)
10. A. cordifolia poorly represented; Hypnum revolutum (a prostrate moss) well represented	PICEA ENGELMANNII/HYPNUM REVOLUTUM h.t. (p.42)

E. Key to Pinus albicaulis Habitat Types

1. Vaccinium scoparium well represented	PINUS ALBICAULIS/VACCINIUM SCOPARIUM h.t. (p.66)
1. V. scoparium poorly represented	2
2. Carex geyeri well represented	PINUS ALBICAULIS/CAREX GEYERI h.t. (p.67)
2. C. geyeri poorly represented	3
3. Juniperus communis, Shepherdia canadensis or Astragalus miser well represented or dominant either singly or collectively	PINUS ALBICAULIS/JUNIPERUS COMMUNIS h.t. (p.67)
3a. Shepherdia canadensis well represented	SHEPHERDIA CANADENSIS phase (p.68)
3b. S. canadensis poorly represented	JUNIPERUS COMMUNIS phase (p.68)
3. Not as above	4
4. Pinus contorta well represented	PINUS ALBICAULIS/CAREX ROSSII h.t. -PINUS CONTORTA phase (p.69)
4. P. contorta poorly represented	5
5. Festuca idahoensis common	PINUS ALBICAULIS/FESTUCA IDAHOENSIS h.t. (p.69)
5. F. idahoensis scarce	PINUS ALBICAULIS/CAREX ROSSII h.t. -CAREX ROSSII phase (p.69)

*H.t.s and phases incidental to study area and omitted from charts and tables.

F. Key to Abies lasiocarpa habitat types

1. Equisetum arvense abundant . . . . PICEA ENGELMANNII/EQUISETUM ARVENSE h.t. (p.36)
1. E. arvense not abundant 2

2. Caltha leptosepala common or Trollius laxus well represented . . . PICEA ENGELMANNII/CALTHA LEPTOSEPALA h.t. (p.37)
2. C. leptosepala scarce and T. laxus poorly represented 3

3. Carex disperma well represented . . . . PICEA ENGELMANNII/CAREX DISPERMA h.t. (p.38)
3. C. disperma poorly represented 4

4. Calamagrostis canadensis or Ledum glandulosum well represented . . . ABIES LASIOCARPA/CALAMAGROSTIS CANADENSIS h.t. (p.45)
  4a. Ledum glandulosum well represented . . . . LEDUM GLANDULOSUM phase* (p.45)
  4b. Not as above; Vaccinium caespitosum common . . . . VACCINIUM CAESPITOSUM phase* (p.45)
  4c. Not as above in 4a or 4b . . . . CALAMAGROSTIS CANADENSIS phase (p.45)
4. C. canadensis and L. glandulosum poorly represented 5

5. Streptopus amplexifolius or Senecio triangularis well represented either separately or collectively . . . . ABIES LASIOCARPA/STREPTOPUS AMPLEXIFOLIUS h. t.* (p.46)
5. Not as above 6

6. Menziesia ferruginea well represented . . . . ABIES LASIOCARPA/MENZIESIA FERRUGINEA h.t.* (p.47)
6. M. ferruginea poorly represented 7

7. Actaea rubra common . . . . ABIES LASIOCARPA/ACTAEA RUBRA h.t. (p.47)
7. A. rubra scarce 8

8. Physocarpus malvaceus well represented . . . . ABIES LASIOCARPA/PHYSOCARPUS MALVACEUS h.t. (p.48)
8. P. malvaceus poorly represented 9

9. Acer glabrum or Sorbus scopulina well represented either separately or collectively . . . . ABIES LASIOCARPA/ACER GLABRUM h.t. (p.48)
9. Not as above 10

10. Linnaea borealis common . . . . ABIES LASIOCARPA/LINNAEA BOREALIS h.t. (p.49)
  10a. Vaccinium scoparium well represented . . . . VACCINIUM SCOPARIUM phase (p.49)
  10b. V. scoparium poorly represented . . . . LINNAEA BOREALIS phase (p.49)
10. L. borealis scarce 11

11. Xerophyllum tenax well represented . . . . ABIES LASIOCARPA/XEROPHYLLUM TENAX h.t.* (p.50)
11. X. tenax poorly represented 12

12. Vaccinium globulare well represented . . . . ABIES LASIOCARPA/VACCINIUM GLOBULARE h.t. (p.50)
  12a. Vaccinium scoparium abundant . . . . VACCINIUM SCOPARIUM phase (p.50)
  12b. V. scoparium not abundant; Pachistima myrsinites usually present, sites mainly south or east of Snake River Plains (fig. 2) . . . . PACHISTIMA MYRSINITES phase (p.50)
  12c. P. myrsinites absent, sites mainly north or west of Snake River Plains . . . . VACCINIUM GLOBULARE phase (p.51)
12. V. globulare poorly represented 13

13. Luzula hitchcockii common . . . . ABIES LASIOCARPA/LUZULA HITCHCOCKII H.T.* (p.52)
13. L. hitchcockii scarce 14

14. Vaccinium scoparium well represented . . . . ABIES LASIOCARPA/VACCINIUM SCOPARIUM h.t. (p.52)
  14a. Calamagrostis rubescens well represented . . . . CALAMAGROSTIS RUBESCENS phase (p.52)
  14b. C. rubescens poorly represented; Pinus albicaulis well represented . . . . PINUS ALBICAULIS phase (p.52)
  14c. Not as above in 14a or 14b . . . . VACCINIUM SCOPARIUM phase (p.52)
14. V. scoparium poorly represented 15

15. Arnica latifolia well represented . . . . ABIES LASIOCARPA/ARNICA LATIFOLIA h.t. (p.53)
15. A. latifolia poorly represented 16

16. Symphoricarpos albus well represented . . . . ABIES LASIOCARPA/SYMPHORICARPOS ALBUS h.t. (p.53)
16. S. albus poorly represented 17

17. Thalictrum occidentale well represented . . . . ABIES LASIOCARPA/THALICTRUM OCCIDENTALE h.t. (p.54)
17. T. occidentale poorly represented 18

18. Osmorhiza chilensis or O. depauperata well represented either separately or collectively . . . . ABIES LASIOCARPA/OSMORHIZA CHILENSIS h.t. (p.54)
  18a. Pachistima myrsinites well represented . . . . PACHISTIMA MYRSINITES phase (p.55)
  18b. P. myrsinites poorly represented . . . . OSMORHIZA CHILENSIS phase (p.55)
18. Not as above 19

19. Spiraea betulifolia well represented . . . . ABIES LASIOCARPA/SPIRAEA BETULIFOLIA h.t. (p.56)
19. S. betulifolia poorly represented 20

20. Calamagrostis rubescens well represented . . . . ABIES LASIOCARPA/CALAMAGROSTIS RUBESCENS h.t. (p.57)
  20a. Pachistima myrsinites well represented . . . . PACHISTIMA MYRSINITES phase (p.57)
  20b. P. myrsinites poorly represented . . . . CALAMAGROSTIS RUBESCENS phase (p.57)
20. C. rubescens poorly represented 21

21. Beberis repens common or Pachistima myrsinites well represented . . . . ABIES LASIOCARPA/BERBERIS REPENS h.t. (p.58)
  21a. Carex geyeri well represented . . . . CAREX GEYERI phase* (p.59)
  21b. C. geyeri poorly represented . . . . BERBERIS REPENS phase (p.59)
21. B. repens scarce and P. myrsinites poorly represented 22

22. Carex geyeri well represented . . . . ABIES LASIOCARPA/CAREX GEYERI h.t.* (p.59)
22. C. geyeri poorly represented 23

23. Juniperus communis well represented . . . . ABIES LASIOCARPA/JUNIPERUS COMMUNIS h.t. (p.59)
23. J. communis poorly represented 24

24. Ribes montigenum well represented or the dominant plant of normally depauperate undergrowths . . . . ABIES LASIOCARPA/RIBES MONTIGENUM h.t. (p.60)
  24a. Pinus albicaulis well represented . . . . PINUS ALBICAULIS phase (p.60)
  24b. P. albicaulis poorly represented . . . . RIBES MONTIGENUM phase (p.60)
24. Not as above 25

25. Pedicularis racemosa common . . . . ABIES LASIOCARPA/PEDICULARIS RACEMOSA h.t. (p.60)
25. P. racemosa scarce 26

26. Arnica cordifolia, Astragalus miser, or Shepherdia canadensis well represented or the dominant undergrowth species . . ABIES LASIOCARPA/ARNICA CORDIFOLIA h.t. (p.61)
  26a. Picea engelmannii abundant . . . . PICEA ENGELMANNII phase (p.62)
  26b. P. engelmannii not abundant; Shepherdia canadensis well represented . . . . SHEPHERDIA CANADENSIS phase (p.62)
  26c. Not as above in 26a or 26b; Astragalus miser common . . . . ASTRAGALUS MISER phase (p.62)
  26d. Not as above in 26a, 26b or 26c . . . . ARNICA CORDIFOLIA phase (p.65)
26. Not as above in 26; Carex rossii well represented or the dominant undergrowth species . . . . ABIES LASIOCARPA/CAREX ROSSII h.t. (p.65)

*H.t.s and phases incidental to study area and omitted from charts and tables.

Descriptions of Series, Habitat Types and Phases

Pinus flexilis Series

Distribution.—The *Pinus flexilis* series denotes some of the driest sites capable of supporting trees (except *Juniperus*) and its distribution is associated with the continental climatic regime (Pfister and others 1977). This series extends from lower treeline where it supports a savanna of *Pinus flexilis* and other dry-site species such as *Juniperus scopulorum, Bouteloua gracilis*, and *Agropyron spicatum* to upper treeline on calcareous substrates. Tree form and spacing is highly dependent upon site conditions. On very rocky sites at the low elevations, *P. flexilis* has a sprawling form (heights <9 m, 30 feet) and is widely spaced. On more favorable sites where true forest vegetation occurs, the pine's lateral growth is suppressed and its growth form is more upright.

Vegetation.—Peet (1978), working primarily in the Rocky Mountains of Colorado and New Mexico, has noted that *P. flexilis* seems to function as a low-altitude dominant and in the absence of *P. aristata* or *P. albicaulis* extends upslope to become a high-elevation dominant. Though he did not examine its ecology in northwestern Wyoming or Idaho, Peet attributed such range restrictions to competitive interactions and ecologic release. For northwestern Wyoming factors other than competition probably account for the absence of *P. albicaulis* and presence of *P. flexilis* in certain regions. Though we did not statistically test the hypothesis, it appears that these two species have strong substrate preferences, evidence for which is slowly accumulating (Pfister and others 1977; Steele and others 1981; Reed 1976). In the Rocky Mountains, *Pinus flexilis* shows a strong preference for calcareous substrates and reduced success on igneous materials which favor *P. albicaulis*. Where *P. flexilis* rarely co-occurs with *P. albicaulis* at moderate elevations (2 680–2 895 m, 8,800–9,500 feet), *P. albicaulis* may have a slightly greater potential to regenerate through its greater shade tolerance, but there is no evidence of competitive exclusion between *P. albicaulis* and *P. flexilis*.

The actual range of habitats where *P. flexilis* dominates is quite narrow though it is distributed from about 1 830 to 3 050 m (6,000 to 10,000 feet) within the study area. At lower tree line or on south and rocky slopes *P. flexilis* may be the only tree present but is usually joined at lower elevations by *Juniperus scopulorum, J. osteosperma*, and to a limited extent by *Cercocarpus ledifolius*. With increasing elevation, *Pseudotsuga* appears more frequently and the balance between *P. flexilis* and *Pseudotsuga* dominance is very tenuous. At the dry forest margins where stands tend to remain open, *P. flexilis* is not excluded by the more shade tolerant *Pseudotsuga*. Many stands now dominated by *P. flexilis* undoubtedly owe their existence to animal seed caches; the most instrumental agent is probably Clarks nutcracker, which transports the wingless seed long distances and caches them on exposed, windswept sites (Lanner and Vander Wall 1980, Lanner 1980). Once such a stand is established at the dry forest margin it is difficult for *Pseudotsuga* to invade the site. Stands thus created, combined with the random effects of fire have maintained a mosaic of vegetation dominated by either *P. flexilis* or *Pseudotsuga* and combinations of the two; this mosaic obviously cannot be understood in terms of site-vegetation relationships alone. *Pinus flexilis* extends as an important seral species (on calcareous substrates) from the *Pseudotsuga* to the *Picea* series. Rarely, it occurs in the *Abies lasiocarpa* series as minor seral species on the driest sites.

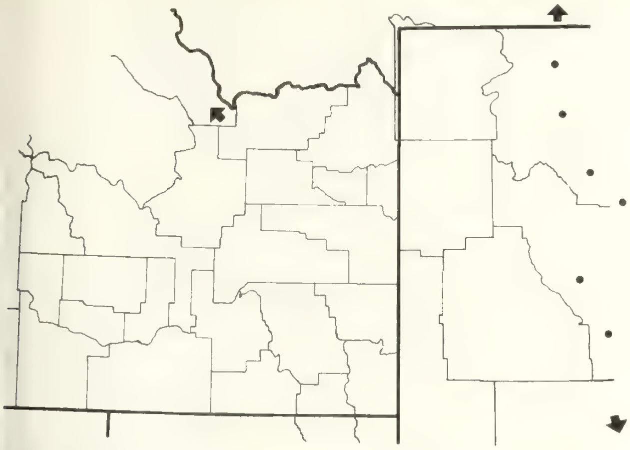
Where *P. flexilis* is the potential climax, it is superimposed over a shrub steppe or grassland community, thus reducing the undergrowth coverage. *Artemisia tridentata* (usually subspecies *vaseyana*), which strongly dominates postfire succession, is shaded out. More shade-tolerant shrubs, such as *Symphoricarpos oreophilus* and *Juniperus communis*, remain in the undergrowth. Caespitose graminoids, such as *Festuca idahoensis*, *Agropyron spicatum*, *Hesperochloa kingii*, or *Carex rossii* may be undergrowth dominants at lower treeline and may maintain their importance to upper treeline on dry exposures. On adjacent drier sites or sites of deep, fine-textured soils (less rock), shrub-steppe or grassland prevails.

Soils/Climate.—Rocky sites with shallow, patchy, duff accumulations and highly erosive soils typify this series. These soils may develop dark surface horizons which reflect a high charcoal content as well as the influence of grasses and forbs. The soils are usually near neutral to slightly basic, reflecting their development on calcareous substrates (appendix D–1). In the Gros Ventre Range, however, *P. flexilis* occurs on red and grey alkaline clay soils (Earle Layser, consultant, Pers. Comm.).

The weather station at Dubois, Wyo. (appendix D–2) approximates the climate of *P. flexilis* savanna that occurs on nearby "bad lands" topography. The Yellowstone Park (Mammoth, Wyo.) station is near a stand of the *PIFL/HEKI* h.t. (appendix D–2). Because virtually all stands of this series are topographic or edaphic climaxes, no conventional weather station can adequately portray the evapotranspirational demand and moisture supply of these sites.

Productivity/Management.—Timber productivity is very low to low, owing to low site indexes and poor form of both *Pinus flexilis* and *Pseudotsuga* and low stockability as denoted by low basal areas. Forage yield is highest where caespitose graminoids dominate early seral stages but decreases drastically with increasing overstory cover on all h.t.'s. The large *P. flexilis* seeds are an important food source for rodents and birds, some of which cache the seeds, and for bears which pilfer the caches. Unexcavated caches may be an important means of *P. flexilis* reproduction.

Pinus Flexilis/Juniperus Communis h.t. (PIFL/JUCO; Limber Pine/Common Juniper)



listribution.—This minor h.t. appears only on the eastern nargin of the study area but ranges into Montana, east-central Idaho, and northwestern Colorado. It occurs on arious aspects from about 2 134 to 2 895 m (7,000 to ,500 feet) and generally appears at low to mid-elevations of the forested zone. Adjacent drier sites are either non-orest h.t.'s or other *Pinus flexilis* h.t.'s. Adjacent more noist sites may be in the *Pseudotsuga, Picea*, or *Abies* eries.

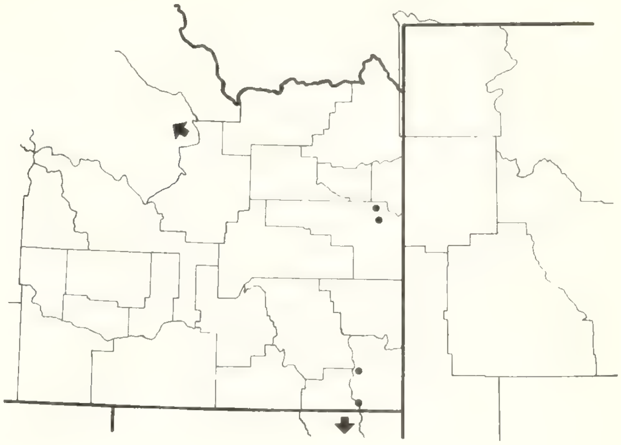
'egetation.—On some noncalcareous sites (particularly andstones), *Pinus contorta* is a minor species thus in-icating that these sites are the most moist of the *PIFL* .t.'s. Otherwise, *Pinus flexilis*, often mixed with *Pseudot-uga* dominate both seral and climax stands. *Juniperus ommunis* is well represented in patches and is joined oc-asionally by *Shepherdia canadensis*. The relatively high onstancy of *Arnica cordifolia* and low constancies of *'esperochloa kingii* and *Agropyron spicatum* reflect the elatively cool moist position of this h.t. in the *Pinus flex-'s* series.

oils.—Sampled soils were derived mainly from limestone nd calcareous sandstone but also from quartzite-sand-tone mixtures, basalt, and granitics. Soil pH ranged from .8 to 7.6 and averaged 6.3. Areas of bare rock reached 0 percent on some sites but areas of bare soil were less an 1 percent. Average litter depths on a site reached 6 n (2.4 in).

roductivity/Management.—Timber production is very low ppendix E-2) and tree regeneration is sporadic. Most tes have some stockability limitations. In some areas, attle make light use of these sites and deer and elk use em for cover.

ther Studies.—Pfister and others (1977) have described is h.t. for Montana ranges east of the Continental vide. Hoffman and Alexander (1980) and Hess (1981) ave described *PIFL/JUCO* in northern Colorado.

Pinus Flexilis/Cercocarpus Ledifolius h.t. (PIFL/CELE; Limber Pine/Curl-Leaf Mountain-Mahogany)



Distribution—*PIFL/CELE* is a minor h.t. that occurs sporadically from east-central Idaho to northern Utah. It extends roughly from 1 829 to 2 590 m (6,000 to 8,500 feet) and usually occupies rocky west-facing to south-facing slopes. Normally this h.t. represents the lower limits of forest trees and merges with *Cercocarpus* dominated communities or shrub steppe communities on adjacent drier sites. Adjacent more moist sites are usually in the *Pseudotsuga* series.

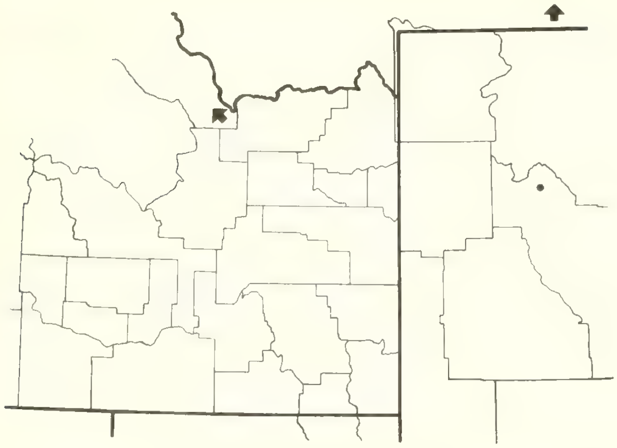
Vegetation.—Open stands of *P. flexilis*, often with *Pseudotsuga*, dominate a somewhat discontinuous layer of *Cercocarpus*. *Juniperus scopulorum* sometimes occurs, appearing comparatively robust, due to the open nature of the stands. *Berberis repens, Symphoricarpos oreophilus*, and *Artemisia tridentata* are common shrubs of widely varying coverage. *Hesperochloa kingii* and *Agropyron spicatum* are the most important grasses and their cover is inversely related to that of the trees and shrubs.

Soils.—Soil parent materials are usually sandstone and limestone. Soil pH data are lacking. Areas of bare rock reached 35 percent and that of bare soil 10 percent. Average litter depth per site reached 9 cm (3.5 in) but was normally about 1 cm (0.4 in).

Productivity/Management.—Timber potentials are quite low (appendix E-2) and regeneration is sporadic. *Cercocarpus* seedlings were not encountered and, in some areas, the size class distribution suggests that *Cercocarpus* may require fire for regeneration (Dealy 1975). The greatest value of existing trees may be the food and cover they provide for rodents, birds, and big game. *Cercocarpus* provides big game with winter cover and important browse but may limit production of forbs and grasses.

Other Studies.—The *PIFL/CELE* h.t. was previously recognized in northern Utah and adjacent Idaho (Henderson and others 1976 unpubl.). It is also described in east-central Idaho (Steele and others 1981).

Pinus Flexilis/Festuca Idahoensis h.t.
(_PIFL/FEID;_ Limber Pine/Idaho Fescue)



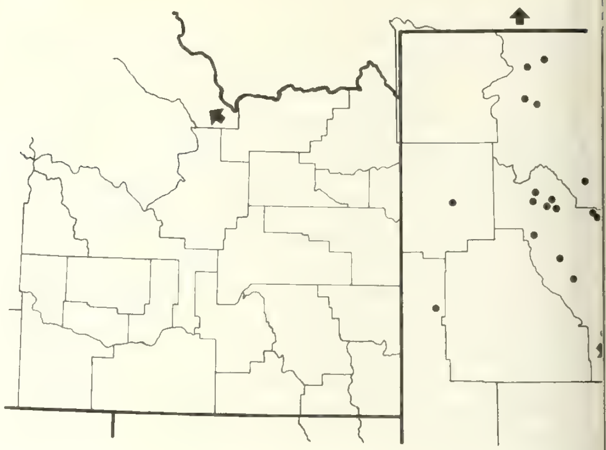
Distribution.—_PIFL/FEID_ is a minor h.t. in the study area and appears mainly in the Absaroka and Owl Creek Ranges of western Wyoming. It shows better development in south-central Montana and east-central Idaho. In the study area, this h.t. ranges from about 2 347 to 2 590 m (7,700 to 8,500 feet) and usually represents a lower timberline condition. At its dry extreme _PIFL/FEID_ occurs as small patches bordering nonforest communities. At the moist extreme it borders the driest h.t.'s of the _Pseudotsuga_ and _Picea_ series.

Vegetation.—_Pinus flexilis_ and _Pseudotsuga_ may be codominant in these open stands. _Festuca idahoensis_ is well represented in the undergrowth and is often accompanied by _Agropyron spicatum_ and _Hesperochloa kingii_. Common forbs include _Balsamorhiza sagittata_ and _Crepis acuminata_. Shrubs are generally sparse.

Productivity/Management.—Timber potentials are low to very low (appendix E-2) and tree regeneration is sporadic and unpredictable. These sites also have stockability limitations. Cattle make some use of the forage on these sites and in some areas big game use the sites for winter range.

Other Studies.—In Montana, Pfister and others (1977) described two phases of _PIFL/FEID_. Only the _Festuca idahoensis_ phase occurs in the study area and it appears comparable to that described in Montana. Small areas of _PIFL/FEID_ also occur in east-central Idaho (Steele and others 1981).

Pinus Flexilis/Hesperochloa Kingii h.t.
(_PIFL/HEKI;_ Limber Pine/Spike-Fescue)



Distribution.—_PIFL/HEKI_ is the most common h.t. of this series. It occurs mainly in the Absaroka and Wind River Ranges and extends to the Medicine Bow Range in southeastern Wyoming. Small amounts also appear in extreme southern Montana and east-central Idaho. Although this h.t. was found as low as 1 585 m (5,200 feet), most stands occur from about 2 195 to 2 804 m (7,200 to 9,200 feet). _PIFL/HEKI_ occupies severe, droughty sites on all aspects, but is usually most extensive on southeast to southwest exposures and may extend from lower to upper treeline on these dry slopes. It frequently exists as a narrow strip between drier sites dominated by nonforest communities and more moist slopes dominated by _Pseudotsuga, Picea_, or _Abies_.

Vegetation.—Widely spaced _P. flexilis_, often accompanied by _Pseudotsuga_, create a savanna-like aspect (fig. 3). In some areas, _Juniperus scopulorum_ is a minor component of the tree layer. _Hesperochloa kingii_, often accompanied by _Agropyron spicatum_, codominate the undergrowth and _Carex rossii_ is often present. Forb coverages are generally low but occasionally _Astragalus miser, Balsamorhiza sagittata_, or _Crepis acuminata_ are well represented. _Artemisia tridentata, Ribes cereum_, and _Symphoricarpos oreophilus_ are the only shrubs that frequently occur in this h.t. and their coverages are usually quite low.

Soils.—Soil parent materials were primarily limestones and sandstones but included rhyolite, andesite, basalt, quartzite, granitics and mixtures of these materials. The pH of soils derived from limestone averaged 7.3 (range from 6.7 to 8.1) whereas that of other parent materials averaged 6.8 (range 6.2 to 7.8). Areas of bare rock reached 20 percent and that of bare soil 30 percent. These values are near the high end of a continuum of forest site conditions and reflect the open, steep, and often rill eroded nature of these sites. Average litter depth per site seldom exceeded 6 cm (2.4 in).

Figure 3.—*Pinus flexilis/Hesperochloa kingii* h.t. in the Bear Creek drainage at the southern end of the Absaroka Range (2 697 m, 8,850 feet). This southwesterly slope represents a dry extreme of the type. *Pinus flexilis* is the only tree present; *Artemisia tridentata* and *Hesperochloa kingii* dominate the undergrowth.

Productivity/Management.—Timber potentials appear low to very low (appendix E-2) due to low stockability and slow height growth. Though this h.t. occurs adjacent to well used rangeland, cattle appear to use it only when slopes are not steep. *PIFL/HEKI* may occur in big game winter range; in local areas along the Hoback and Gros Ventre Rivers, mule deer and bighorn sheep use these sites heavily.

Other Studies.—Cooper (1975) described this h.t. in the study area as the *PSME-PIFL/HEKI* h.t. Pfister and others (1977) note that the portion of their *Pinus flexilis/ Agropyron spicatum* h.t. in southern Montana contains *Hesperochloa* and is similar to *PIFL/HEKI*. The *PIFL/HEKI* h.t. is also described in the Medicine Bow Mountains of southeastern Wyoming (Wirsing and Alexander 1975) and small amounts appear in east-central Idaho (Steele and others 1981).

Pseudotsuga menziesii Series

Distribution.—The *Pseudotsuga menziesii* series ranges from about 1 646 m (5,400 feet) along the Snake River to 2 896 m (9,500 feet) in the Wind River Range and forms the lower timberline in much of the study area. Exceptions are found in the Cassia division of the Sawtooth National Forest where naturally occurring *Pseudotsuga* is inexplicably absent and in portions of the Wind River and Absaroka ranges where the climate is too cold or where the substrate is unsuitable, such as rhyolite or granitics. The *Pseudotsuga* series is most extensive in the eastern Idaho portion of the study area but diminishes eastward as a result of increasing base elevations and, near its eastern limits, the unsuitable substrates. At its warm, dry extreme, the *Pseudotsuga* series merges with mountain shrub communities containing *Cercocarpus, Prunus* or *Symphoricarpos oreophilus* or steppe vegetation containing *Agropyron spicatum, Festuca idahoensis*, or *Hesperochloa*. At the cool, moist extreme, it meets either the *Picea engelmannii* or *Abies lasiocarpa* series.

As Cooper (1975) noted, several species characteristic of *Pseudotsuga* h.t.'s in Idaho and Montana become scarce in parts of the study area. *Symphoricarpos oreophilus*, a ubiquitous species of *Pseudotsuga* h.t.'s in central and southern Idaho, is largely absent in the northeastern portion of the study area. *Symphoricarpos albus* is common in the north and extends southward to about the latitude of Alpine, Wyo. *Calamagrostis rubescens*, a widespread species, becomes scarce in eastern portions of the study area and is absent throughout much of the Wind River

Range. *Pachistima myrsinites*, extending northward from Utah and Colorado, shows good development to about the latitude of Driggs, Idaho. It also has spotty occurrences in Yellowstone Park and near Hebgen Lake in southern Montana. The geographic limits of these indicator species, some extending from different regions, reflect the convergence of different environmental and floristic elements within the study area.

Vegetation.—*Pinus contorta* is the major seral conifer in part of this series and small amounts of *Pinus flexilis* appear in some h.t.'s (appendix B). In a few types, *Populus tremuloides* dominates seral stands, but in many areas only *Pseudotsuga* appears capable of occupying the site. Undergrowths can vary from dense layers of tall shrubs to a sparse cover of low forbs or dry-site grasses.

Soil/Climate.—In most of the study area the *Pseudotsuga* series normally represents the warmer, lower elevation zone of the forest. In some areas, however, *Pseudotsuga* is also dependant on substrate. Then it exhibits a strong preference for limestone and basic extrusive volcanics, particularly andesite and basalt. *Pseudotsuga* is weakly represented on granitics and acidic extrusives such as rhyolite. These relationships are most evident on the eastern flank of the Wind River and Absaroka Ranges which have the strongest continental climatic pattern in the study area. Similar relationships are also noted in the Bighorn Mountains to the east (Despain 1973). Where granitics or rhyolite are prevalent in these areas, *Picea*, *Abies*, or *Pinus contorta* communities often form the lower timberline.

Fire.—Fire has repeatedly altered most vegetation in the *Pseudotsuga* series. Fire-induced communities vary considerably with h.t., but high coverages of *Pinus contorta, Populus tremuloides, Shepherdia canadensis, Ceanothus velutinus*, and *Calamagrostis rubescens* may indicate a history of severe or repeated burning. In some h.t.'s these species, commonly associated with recent burning, will not appear. Instead, vegetation on adjacent more severe sites, such as the mountain shrub communities, simply invades the newly burned area.

Productivity/Management.—Productivity and management vary widely in this series and are best noted in the h.t. descriptions. Nevertheless, a few generalities apply to portions of this series.

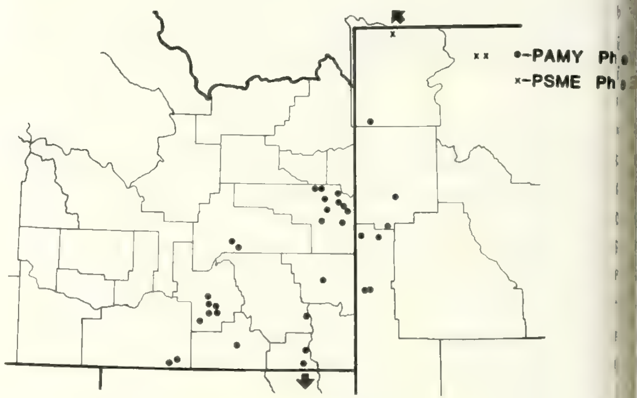
Where *Pinus contorta* is the major seral tree, usually it can be regenerated faster and more easily than *Pseudotsuga*. On these sites *P. contorta* should regenerate adequately in clearings that receive full sunlight. In most areas, many of the cones are nonserotinous, thus burning may only be needed to dispose of slash or trees infested with disease or insects.

Populus tremuloides is a major seral species in the southern half of the study area. When conifers are removed, the *Populus* may quickly dominate these sites an severely restrict establishment and growth of conifer seedlings. Timber harvest methods that maintain a conife canopy will suppress development of *Populus*-dominated stands.

In much of the study area, *Calamagrostis rubescens* responds to fire or logging and develops a dense sod that hinders tree regeneration. These conditions often require careful site preparation before tree seedlings will become established. Although chemicals will effectively destroy the sod (Stewart and Beebe 1974), thorough scarification should be adequate for establishing *Pinus contorta* in the study area.

In southern portions of the study area, *Carex rossii* may invade recent clearcuts before they are adequately restocked. Foliar coverage of the *Carex* can be deceptively low and appear as insignificant competition for tree seedlings. In reality, the *Carex* occupies a much larger soil volume than its foliage would indicate and may be fully occupying the site. In these cases, some form of scarification may be needed to attain adequate tree stocking.

Pseudotsuga menziesii/Physocarpus malvaceus h.t. (*PSME/PHMA*; Douglas-fir/ninebark)



Distribution.—*PSME/PHMA* is a minor h.t. within the study area but is common at low elevations in the Snake, Hoback, and Greys River drainages. It also extends intermittently southward into the Bear River drainage and northward into the Yellowstone drainage. *PSME/PHMA* occurs mainly on steep northerly aspects and other moist, protected slopes from 1 646 to 2 286 m (5,400 to 7,500 feet). It represents moderate environments at low to mid-elevations of the forested zone.

Vegetation.—Normally *Pseudotsuga* dominates both seral ınd old growth stands. In the seral stands, small amounts ıf *Pinus flexilis* and occasionally *Populus tremuloides* nay appear but *Pinus contorta* seldom grows here. *Physo-* *:arpus malvaceus* usually forms a dominant layer in the ındergrowth.

'achistima myrsinites (*PAMY*) phase.—The *PAMY* phase ıccurs from about 1 646 to 2 073 m (5,400 to 6,800 feet) in he Snake, Hoback, Greys and Bear River drainages. It ılso extends southward into Utah. *Pachistima* is usually ıresent and often well represented. This phase represents geographic variant of the *PSME/PHMA* h.t.

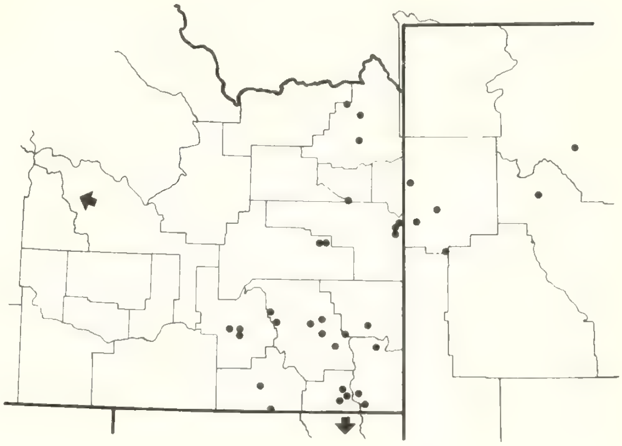
'seudotsuga menziesii (*PSME*) phase.—In the study area, he *PSME* phase occurs mainly in the Yellowstone River rainage, where it ranges from about 1 920 to 2 286 m ;,300 to 7,500 feet). It also extends from southern Mon- ana to east-central Idaho. In some areas, the upper limits f this phase grade into a *PIEN/PHMA* h.t.

oils.—Soils in the *PAMY* phase were derived mainly from mestone and sandstone. Those in the *PSME* phase were erived mainly from andesite and occasionally limestone. oil pH ranged from 6.6 to 7.5 and averaged 7.0 in the *'AMY* phase. There is insufficient pH data for the *PSME* hase. In both phases, coverages of bare rock and soil 'ere usually less than 5 percent and average litter depth n a site reached 10 cm (3.9 in).

roductivity/Management.—*Pseudotsuga* is the most uitable timber species for these sites. It appears to egenerate readily in small openings but growth rates are ıw to moderate (appendix E). If the tree canopy is re- ıoved, the shrub layer may increase and suppress conifer eedlings. This is especially true when insects or wildfire ll the trees and the site is left unscarified. Domestic vestock find little forage here but big game may use ıese sites for cover and escape. The low elevations of ıese sites may attract heavy big game use in winter even ıough suitable browse is often scarce on timbered sites. *cer, Amelanchier, Salix*, and *Pachistima* (appendix C) ay be important browse species on nontimbered sites.

ther Studies.—Cooper (1975) and Henderson and others 976 unpubl.) have previously described this h.t. within e study area. *PSME/PHMA* is a major h.t. in Montana fister and others 1977), central Idaho (Steele and others 981), and northern Idaho (Daubenmire and Daubenmire 968).

Pseudotsuga menziesii/Acer glabrum h.t. (*PSME/ACGL*; Douglas-fir/mountain maple)



Distribution.—This h.t. is best developed in the southeastern quarter of Idaho and in adjacent Wyoming and parts of northern Utah. Other phases of this type extend through much of central Idaho. The *Pachistima myrsinites* (*PAMY*) phase serves as a geographic distinction for the study area. The *PSME/ACGL* h.t., *PAMY* phase occurs from about 1 829 to 2 530 m (6,000 to 8,300 feet) on moist, northerly aspects that are often quite steep. These sites normally represent low to middle elevations of the *Pseudotsuga* series and appear cooler than the *PSME/PHMA* h.t.

Vegetation.—Generally, *Pseudotsuga* is the dominant tree in all successional stages. Occasionally small amounts of *Populus tremuloides* or *Pinus flexilis* may be present. A tall layer of *Acer, Amelanchier*, and *Prunus* dominates seral undergrowths. Toward climax, *Acer glabrum* or *Sorbus scopulina* becomes the dominant shrub (fig 4). *Pachistima* and *Berberis* are usually present though often sparse. Numerous forbs are often present, of which *Arnica, Osmorhiza*, and *Galium triflorum* are most common. *Calamagrostis rubescens* and *Carex geyeri* are often conspicuous. This h.t. may represent the most moist uplands in the area or it may border the *ABLA/ACGL* or *ABLA/ACRU* h.t.'s. Adjacent drier sites are usually *PSME/OSCH* or *PSME/CARU* h.t.'s or sometimes support *Acer grandidentatum* communities.

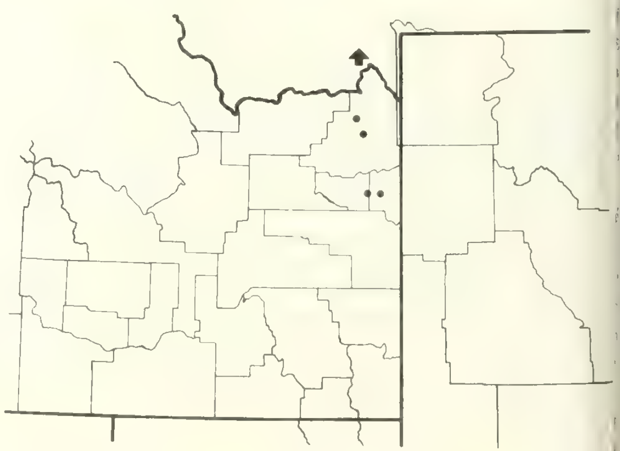
Soils.—*PSME/ACGL* was found mainly on sedimentary soil parent materials and many of these were also calcareous. Soil pH ranged from 6.0 to 7.2 and averaged 6.6. Areas of bare rock varied considerably and reached 50 percent. Areas of bare soil are usually less than 2 percent. Average litter depth on a site reached 7 cm (2.8 in.).

Figure 4.—*Pseudotsuga menziesii/Acer glabrum* h.t., *Pachistima* phase on a north slope in upper Wolverine Canyon southeast of Idaho Falls, Idaho (2 164 m, 7,100 feet). *Pseudotsuga* has formed a pure, all-aged stand on the site. Large sprawling *Acer* dominate the undergrowth; the less tolerant shrubs *Amelanchier and Prunus* are declining. *Arnica cordifolia* is the conspicuous forb.

Productivity/Management.—*Pseudotsuga* is the best suited timber species. Its productivity is moderate (appendix E-2). The seedlings should establish best in small openings protected from severe sun and wind. Overstory removal may stimulate development of a tall shrub layer that is beneficial to big game but may retard the growth of conifer seedlings. Domestic livestock seldom use these sites because of the steep slopes and more desirable forage in adjacent areas.

Other Studies.—Henderson and others (1976 unpubl.) previously described this h.t. in southeastern Idaho. In central Idaho, a *Symphoricarpos oreophilus* phase and an *Acer glabrum* phase were recognized (Steele and others 1981). Hoffman and Alexander (1980) describe a *Pseudotsuga menziesii/Pachistima myrsinites* h.t. in northwestern Colorado that appears related to the *PSME/ACGL* h.t., *PAMY* phase.

***Pseudotsuga menziesii/Vaccinium globulare* h.t. (*PSME/VAGL;* Douglas-fir/blue huckleberry)**



istribution.—This minor h.t. occurs mainly in Montana ut was found on the Targhee National Forest from the entennial Mountains south to the Snake River Range. It ccurs from about 1 951 to 2 255 m (6,400 to 7,400 feet) on oderately steep slopes having northerly aspects.

egetation.—*Pinus contorta* is a major seral tree in this t. and usually invades following fire. *Pseudotsuga* is the nly other tree normally found here. *Vaccinium globulare* sually dominates a shrubby undergrowth that includes *piraea betulifolia* and *Lonicera utahensis*. *Calamagrostis bescens* is usually present.

roductivity/Management.—*Pinus contorta* should generate readily wherever the tree canopy is removed nd the seedbed is suitable. *Pseudotsuga* seedlings may enefit from a light tree canopy, but the undergrowth of hrubs and grass can impede their establishment. In sumer and fall, big game may seek food and cover on these entle northerly aspects and the fall berry crops attract ears, grouse and humans. Occasional spring burning of e undergrowth (Miller 1977) and a partial tree canopy ay provide the best maintenance for berry production.

ther Studies.—Cooper (1975) first described *PSME/VAGL* om this area. Several phases of this h.t. occur in Monna (Pfister and others 1977) and occasionally in central aho (Steele and others 1981). Only the *Vaccinium obulare* phase occurs in the study area.

seudotsuga menziesii/Physocarpus monogynus h.t. *SME/PHMO;* Douglas-fir/mountain ninebark)

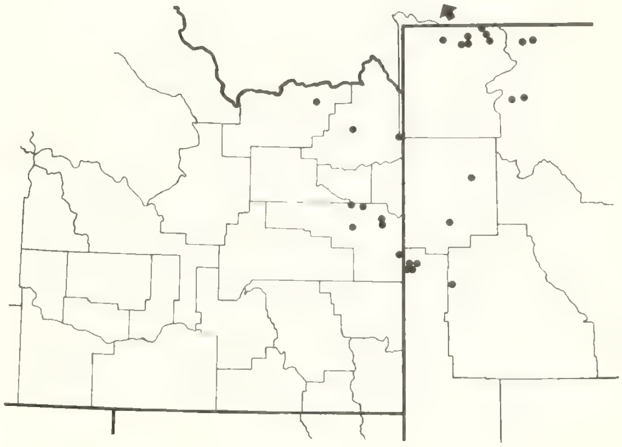
stribution.—This incidental h.t. occurs mainly in the ghorn Mountains of Wyoming. In our study area it was und only in the Wind River Canyon. Here it occupies eep north aspects at about 1 859 m (6,100 feet). Observans of *PSME/PHMO* in the Bighorn Mountains suggest at it is a geographic replacement of the *PSME/PHMA* ., *PSME* phase, which it strongly resembles in aparance and topographic position.

getation.—*Pseudotsuga* dominates the site, with small nounts of *Pinus flexilis* and *Juniperus scopulorum* scated throughout. *Physocarpus monogynus* dominates the dergrowth. Only small amounts of other shrubs or forbs e present, but there is a notable moss layer. *P. onogynus* strongly resembles *P. malvaceus*; mature iits are needed for positive identification (see Taxomic Considerations).

oductivity/Management.—Although general management guidelines may follow those of *PSME/PHMA* h.t., *ME* phase, the overall productivity and vegetal response *PSME/PHMO* may be considerably less, due to a more vere environment. *Pseudotsuga* is the only suitable nber species for these sites. Its regeneration may be oradic and may face severe competition from the layer *Physocarpus*. These sites may occur near big game ntering areas and provide important cover but forage ues are probably lower than in *PSME/PHMA* because e seral browse species *Acer*, *Amelanchier*, and *Salix* are rmally lacking.

Other Studies.—*PSME/PHMO* is reported from the Bighorn Mountains of Wyoming (Hoffman and Alexander 1976) and the Front Range of Colorado (Hess 1981).

Pseudotsuga menziesii/Symphoricarpos albus h.t. (*PSME/SYAL;* Douglas-fir/common snowberry)



Distribution.—*PSME/SYAL* occurs as a minor type from about Alpine, Wyo., northward into Montana and northwestern Wyoming. It occupies low elevation slopes and benches having relatively mild climates and deep moist soils. *PSME/SYAL* appears most often from 1 737 to 2 255 m (5,700 to 7,400 feet) on southerly to easterly aspects. Adjacent cooler sites are usually an *Abies lasiocarpa* h.t. and adjacent drier sites are usually a *PSME/CARU* or nonforest h.t.

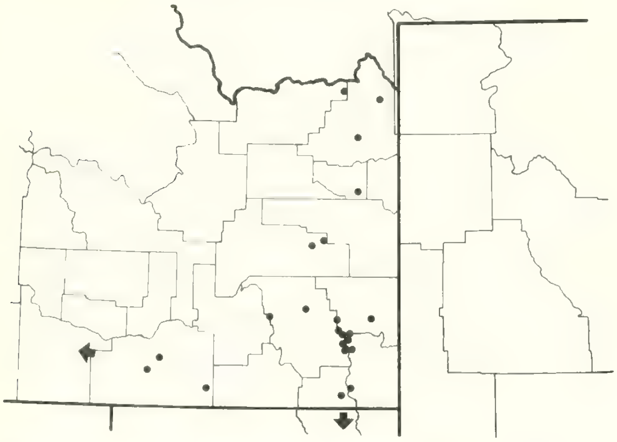
Vegetation.—*Populus tremuloides, Pinus contorta* and small amounts of *Pinus flexilis* are the common seral trees in various portions of the h.t. *Pseudotsuga* usually codominates with these species in the later seral stages. Usually *Symphoricarpos albus* forms a low shrub layer with *Spiraea betulifolia* and *Berberis repens*. *Prunus* and *Amelanchier* are often present. On some sites, *Calamagrostis rubescens* forms a layer beneath the shrubs.

Soils.—Soil parent materials were mainly limestone, sandstone, or basic volcanics. Soil pH ranged from 5.9 to 7.5 and averaged 6.7. Areas of bare soil and rock were usually less than 2 percent. Average litter depth on a site reached 10 cm (3.9 in.), but was normally closer to 4 cm (1.6 in).

Productivity/Management.—On most sites, *Pseudotsuga* is the only species suitable for timber production and its productivity ranges from low to moderate (appendix E-2). It should regenerate well in small, protected openings. If *Populus tremuloides* is present, the *Populus* may increase rapidly after conifers are burned or harvested and retard growth of *Pseudotsuga* seedlings. Young shoots of *Populus* can provide browse for big game and sometimes such sites are important wintering areas. Domestic livestock show little preference for these sites but may use them as resting areas.

Other Studies.—Cooper (1975) first described a *PSME/SYAL* h.t. in this area, but he defined a much broader unit than recognized here. Although several phases of *PSME/SYAL* are reported from Montana (Pfister and others 1977) and central Idaho (Steele and others 1981), only the *Symphoricarpos albus* phase is recognized in our study area. *PSME/SYAL* also occurs in northern Idaho (Daubenmire and Daubenmire 1968).

Pseudotsuga menziesii/Osmorhiza chilensis h.t. (*PSME/OSCH*; Douglas-fir/mountain sweet-root)



Distribution.—*PSME/OSCH* is a major h.t. across the southern portion of Idaho and into northern Utah. It also extends sporadically northward to Montana. It ranges from 1 768 to 2 377 m (5,800 to 7,800 feet) and usually appears on the slopes of ridges that are adjacent to the Snake River Plain or related desert. The slopes in general are moderate to steep and have northerly aspects. Most sites occur near lower timberline and adjacent warmer sites are often nonforested.

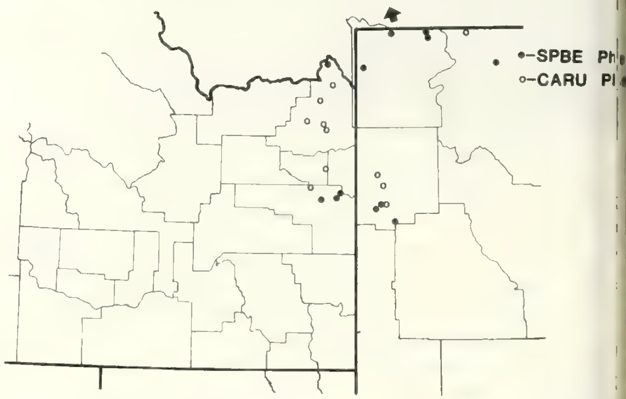
Vegetation.—Normally *Pseudotsuga* is the only conifer on these sites although an occasional *Abies lasiocarpa* may be present. *Populus tremuloides* and sometimes *Pinus contorta* may dominate seral stands. Members of adjacent mountain shrub communities, which may include *Prunus virginiana, Symphoricarpos oreophilus, Amelanchier alnifolia*, and *Acer grandidentatum*, can also invade disturbed sites (fig. 5). *Osmorhiza chilensis*, or sometimes *O. depauperata* usually dominates a layer of forbs that includes *Smilacina racemosa* and *Viola nuttallii*. The moss, *Eurhynchium pulchellum*, appears frequently in this h.t., particularly on the bases of trees. Where the *PSME/CARU* or *PSME/CAGE* h.t. is nearby on drier sites, *Calamagrostis* or *Carex* may be well represented, especially in younger stands.

Soils.—Soil parent materials are mainly sedimentary and include sandstone, shale, and quartzite. Soil pH varies from 5.3 to 6.6 and averages 6.0. Areas of bare rock and soil are usually less than 2 percent. Average litter depths on a site can reach 9.5 cm (3.7 in).

Productivity/Management.—Timber productivity ranges mostly from moderate to high in this h.t. (appendix E-2). *Pseudotsuga* is often the only conifer adapted to the site and regenerates well in the shade of older trees. If present, *Populus tremuloides* can quickly dominate cleared areas in this h.t. Pocket gophers are sometimes numerous and can pose a threat to young conifers. Domestic livestock often use these sites for resting and shelter but seldom find much forage here. Big game use is normally light but may increase in early seral stages.

Other Studies.—This h.t. was first described in the southern Sawtooth National Forest (Steele and others 1974 unpubl.). It was subsequently recognized by Henderson and others (1976 unpubl.) in our study area and by Steele and others (1981) in central Idaho. No other studies have reported a *PSME/OSCH* h.t.

Pseudotsuga menziesii/Spiraea betulifolia h.t. (*PSME/SPBE*; Douglas-fir/white spirea)



Distribution.—This minor h.t. occurs from about Alpine, Wyo., northward to Yellowstone Park and into Montana. It ranges from about 1 829 to 2 499 m (6,000 to 8,200 feet) on upper slopes and ridges having various aspects. *PSME/SPBE* normally represents a mid-elevation segment of the *Pseudotsuga* series.

Figure 5.—*Pseudotsuga menziesii/Osmorhiza chilensis* h.t. on a gentle north slope on Scout Mountain south of Pocatello, Idaho (1 996 m, 6,550 feet). All-age *Pseudotsuga* and an occasional *Populus tremuloides* comprise the tree layer. Scattered intolerant shrubs, *Symphoricarpos oreophilus, Amelanchier*, and *Prunus* are slowly declining. *Osmorhiza* dominates a conspicuous layer of forbs.

Vegetation.—Occasionally *Pinus contorta* grows here as a seral species and codominates the site with *Pseudotsuga*. In many areas, however, *Pseudotsuga* dominates both seral and old-growth stands. Normally, *Spiraea betulifolia* is a major component of a low shrub layer that sometimes includes high coverages of *Pachistima*. Lesser amounts of *Amelanchier* and *Symphoricarpos oreophilus* are also common.

Calamagrostis rubescens (*CARU*) phase.—This phase was found from 1 829 to 2 408 m (6,000 to 7,900 feet) and often occurs in the same area as the *SPBE* phase. Thus it appears influenced by minor differences in soil and temperature. *Pinus contorta* is more abundant here than in the *SPBE* phase. A conspicuous layer of *Calamagrostis rubescens* often mixed with *Carex geyeri* is the characteristic feature of the *CARU* phase. It is often transitional to a *PSME/CARU* or *ABLA/CARU* h.t. and its vegetal response to disturbance is apt to be similar to these types. *Populus tremuloides* may occur in small amounts but shows limited potential for colonizing the site.

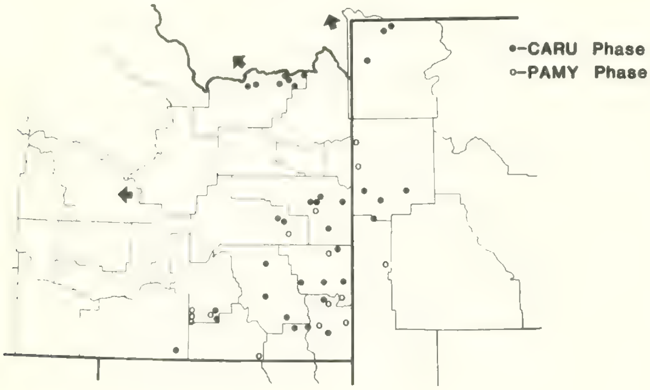
Spiraea betulifolia (*SPBE*) phase.—This phase was found from 2 012 to 2 499 m (6,600 to 8,200 feet) and occurs throughout the distribution of the h.t. Small amounts of *Pinus flexilis* may be present in this phase. Otherwise it fits the description given for the h.t.

Soils.—Soil parent materials included limestone, sandstone, quartzite and andesite. The pH ranged from 5.7 to 6.7 and averaged 6.3. Areas of bare rock varied but reached 20 percent. Areas of bare soil were generally nil. Average litter depths on a site reached 9 cm (3.5 in).

Productivity/Management.—Timber productivity potential is low to moderate (appendix E-2). *Pseudotsuga* is the only suitable timber species for many of these sites and may require careful site preparation for adequate restocking, especially in the *CARU* phase. Seedlings may require small openings that provide protection from wind or sun. If present, *Pinus contorta* may be a more feasible species for regenerating the stand and will establish in larger openings. Most of these sites receive light use from big game, but in some areas they receive heavy winter use. Domestic livestock use this h.t. sparingly.

Other studies.—The *PSME/SPBE* h.t. is also reported from Montana (Pfister and others 1977) and central Idaho (Steele and others 1981).

Pseudotsuga menziesii/Calamagrostis rubescens h.t. (*PSME/CARU;* Douglas-fir/pinegrass)



Distribution.—*PSME/CARU* is a major h.t. throughout much of the study area but is very scarce along the eastern periphery, especially in the Wind River Range. It is also widespread in central Idaho and parts of Montana. *PSME/CARU* usually occupies upper slopes and ridges from 1 829 to 2 469 m (6,000 to 8,100 feet) where various cool, dry aspects have gentle to moderate relief. It normally occurs at the middle to upper elevations of the *Pseudotsuga* series.

Vegetation.—*Pinus contorta* may dominate some seral stands and *P. flexilis* may appear in small amounts. Occasionally *Populus tremuloides* will dominate early seral stands. Otherwise *Pseudotsuga* is the only conifer adapted to the site. Undergrowths vary between the phases listed below.

Pachistima myrsinites (*PAMY*) phase.—This minor phase occurs in southeastern Idaho and adjacent Wyoming where it ranges from about 1 829 to 2 347 m (6,000 to 7,700 feet). A layer of *Pachistima* overtops the *Calamagrostis* and creates a characteristic feature of this phase (fig. 6). *Berberis repens, Prunus virginiana* and *Symphoricarpos oreophilus* are usually present.

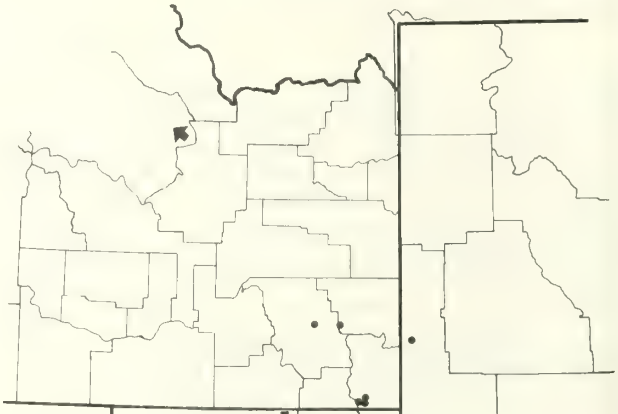
Calamagrostis rubescens (*CARU*) phase.—This is the common phase of the *PSME/CARU* h.t. In the study area it occurs from about 1 829 to 2 469 m (6,000 to 8,100 feet). A low, dense layer of *Calamagrostis* usually dominates the undergrowth (fig. 7). Shrubs and forbs are normally sparse in old, undisturbed stands but in some areas *Symphoricarpos oreophilus* is well represented. Sometimes the *Symphoricarpos* indicates rocky slopes with inherently low tree stockability, but in other areas the *Symphoricarpos* merely invades openings following disturbance of the undergrowth.

Soils.—Soil parent materials were mainly limestone, sandstone, and shale. One site was on rhyolite. Calcareous substrates were common in the *PAMY* phase as opposed to the *CARU* phase. Soil pH ranged from 4.7 to 7.0 and averaged 6.0. Areas of bare soil and rock were usually nil. Average litter depths on a site reached 9.5 cm (3.7 in.) but were usually around 2-3 cm (0.8-1.2 in).

Productivity/Management .—Timber productivity ranges from low to moderate (appendix E-2). Forage production will vary inversely with amount of overstory. When the overstory is reduced, *Calamagrostis* can rapidly develop a thick sod that often requires scarification for successful conifer regeneration. When present, *Pinus contorta* can be regenerated in openings that receive full sunlight provided the site is adequately treated and protected from grazing animals. Lotan and Perry (1977) suggest possible seed: seedling survival ratios for *Pinus contorta* following various site treatments. When *Pseudotsuga* is the only conifer adapted to the site, the seedlings often require protection from wind and sun. In the *CARU* phase, various amounts of *Symphoricarpos oreophilus, Amelanchier*, and *Prunus* may appear in early seral stages but burned areas often return directly to an undergrowth of *Calamagrostis* and *Carex geyeri*.

Other Studies.—The *PSME/CARU* h.t. was previously described in our area by Cooper (1975) and Henderson and others (1976 unpubl.). It was also noted in Montana (Pfister and others 1977) and central Idaho (Steele and others 1981).

Pseudotsuga menziesii/Cercocarpus ledifolius h.t. (*PSME/CELE;* Douglas-fir/curl-leaf mountain-mahogany)



Distribution.—This minor h.t. occurs mainly in the southeastern Idaho portion of the study area but also exists in northern Utah and east-central Idaho. It occurs from 1 890 to 2 255 m (6,200 to 7,400 feet) on a variety of slopes and aspects at or near lower timberline and often borders a *Cercocarpus* shrub community on drier sites. At its moist extreme, it merges with *Pseudotsuga* h.t.'s having denser tree canopies.

Figure 6.—*Pseudotsuga menziesii/Calamagrostis rubescens* h.t., *Pachistima* phase on a north slope in Montpelier Canyon just east of Montpelier, Idaho (2 060 m, 6,760 feet). Pole size *Pinus contorta* and scattered large *Pseudotsuga* dominate the site. *Pachistima* and *Calamagrostis* are the predominate undergrowth species.

Figure 7.—*Pseudotsuga menziesii/Calamagrostis rubescens* h.t., *Calamagrostis* phase on a steep east slope overlooking the Snake River east of Alpine, Wyo. (1 829 m, 6,000 feet). All-age *Pseudotsuga*, and some *Pinus contorta*, dominate a sward of *Calamagrostis rubescens*. An unusually high coverage of *Aster conspicuus* complements the herbaceous layer on this particular site.

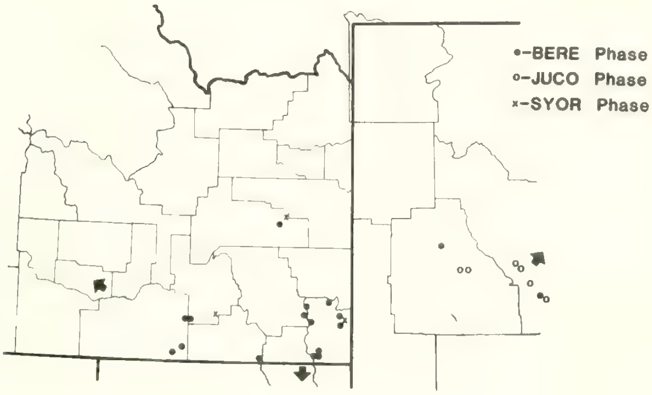
Vegetation.—Trees are often widely scattered. *Pseudotsuga* is usually the only tree present but *Juniperus scopulorum* and small amounts of *Pinus flexilis* may occur. A dense layer of *Cercocarpus* dominates the tree interspaces. Either *Symphoricarpos oreophilus* or *Agropyron spicatum* may form a subordinate layer.

Soils.—Soil parent materials were mainly sandstone and limestone. The pH ranged from 6.8 to 7.5 and averaged 7.2. Coverage of bare rock reached 20 percent on some sites; areas of bare soil reached 5 percent. Average litter depth per site reached 7 cm (2.8 in).

Productivity/Management.—Timber productivity potential is low to very low (appendix E-2), due to low basal areas (stockability limitations) and low site index. Tree regeneration is sporadic. Domestic livestock find sparse forage here, perhaps because of the dense layer of shrubs. In many areas, the *Cercocarpus* provides important food and cover for big game.

Other Studies.—The *PSME/CELE* h.t. was previously recorded in southeastern Idaho (Henderson and others 1976 unpubl.) and in east-central Idaho (Steele and others 1981). It has not been described in other adjacent areas.

Pseudotsuga menziesii/Berberis repens h.t. (*PSME/BERE;* Douglas-fir/Oregon grape)



Distribution.—*PSME/BERE* is a major h.t. in southeastern Idaho and adjacent Utah. It also occurs in extreme south-central Idaho and appears sporadically in the Wind River and Bighorn Mountains of Wyoming. It ranges from 1 737 to 2 591 m (5,700 to 8,500 feet) and occupies a variety of aspects at low to mid-elevations of the forested zone. Adjacent drier sites are generally a *PSME/SYOR* or nonforest h.t.

Vegetation.—*Populus tremuloides, Pinus contorta*, and *Pinus flexilis* are common seral species that vary in abundance according to the phases noted below. When present, these species usually codominate with *Pseudotsuga* in seral stands, but in many areas *Pseudotsuga* is the only tree capable of occupying the site. *Berberis repens* and in some areas *Pachistima myrsinites* form a conspicuous layer in old-growth stands. *Prunus virginiana* and *Symphoricarpos oreophilus* often dominate the undergrowth of seral stands. *Smilacina racemosa* and *Arnica cordifolia* are the most common forbs.

Carex geyeri (*CAGE*) phase.—This incidental phase appears mainly in central Idaho and also in the Uinta Mountains. It was noted locally in our study area at about 2 195 m (7 200 feet) along the western flank of the Teton Range. Here *Pinus contorta* is a minor seral species and *Carex geyeri* forms a prominent layer in the undergrowth (fig. 8).

Juniperus communis (*JUCO*) phase.—The *JUCO* phase occurs mainly in the Bighorn Mountains to the east of our study area (fig. 9). It also occurs locally in the Wind River Range from about 2 347 to 2 591 m (7,700 to 8,500 feet). In this area it appears on northerly aspects having gentle to moderately steep slopes. *Populus tremuloides* and *Pinus contorta* may dominate seral stands and *Pinus flexilis* is often present. Usually *Juniperus communis* is well represented in the undergrowth.

Symphoricarpos oreophilus (*SYOR*) phase.—This phase appears sporadically in southeastern Idaho and along the southern periphery of central Idaho. In the study area it was found on southerly aspects from about 2 012 to 2 255 m (6,600 to 7,400 feet). The *SYOR* phase usually borders nonforest communities that contain *Symphoricarpos oreophilus*. Small amounts of *Pinus flexilis* and *Juniperus scopulorum* may occur, but usually *Pseudotsuga* is the only tree present. *Prunus, Amelanchier*, and *Artemisia* often accompany the *Symphoricarpos*. Trees are widely spaced so that even in old-growth stands these shrubs are never shaded out (fig. 10).

Berberis repens (*BERE*) phase.—This is the most common phase in the study area. It generally occurs on northerly aspects from 1 737 to 2 438 m (5,700 to 8,000 feet). A few seral stands may be dominated by *Populus tremuloides* or *Pinus contorta*, and *Pinus flexilis* may be present. In older stands the *Pseudotsuga* can develop a dense canopy that suppresses the taller shrubs and leaves *Berberis* or *Pachistima* to dominate the undergrowth (fig. 11).

Soils.—Soil parent materials were mainly sandstone or limestone in all phases. In the *BERE* phase, soil pH ranged from 6.1 to 7.7 and averaged 6.5. In the *JUCO* phase, it averaged 6.6 (6.2 to 7.2). Coverages of bare rock and bare soil seldom exceeded 3 percent. Average litter depth on a site reached 10 cm (3.9 in). Other soils data are lacking.

Productivity/Management.—Timber productivity appears moderate to high in the *BERE* phase (appendix E-2) and is probably less in the *JUCO* phase. The *SYOR* phase has little timber potential. *Pseudotsuga* seedlings may require openings small enough to receive protection from wind and sun. Cattle may use these sites for rest and shelter, especially when grazing areas are nearby. Light use by big game was noted in much of this h.t. and the *SYOR* phase often receives moderate big game use.

Figure 8.—*Pseudotsuga menziesii/Berberis repens* h.t., *Carex geyeri* phase in the Badger Creek drainage, west slope of the Teton Range (2 195 m, 7,200 feet). All-age *Pseudotsuga* and minor amounts of *Pinus contorta* dominate this gentle southeast slope. *Pachistima*, *Berberis*, *Amelanchier*, and *Prunus* are the prominent shrubs over a dense layer of *Carex geyeri*.

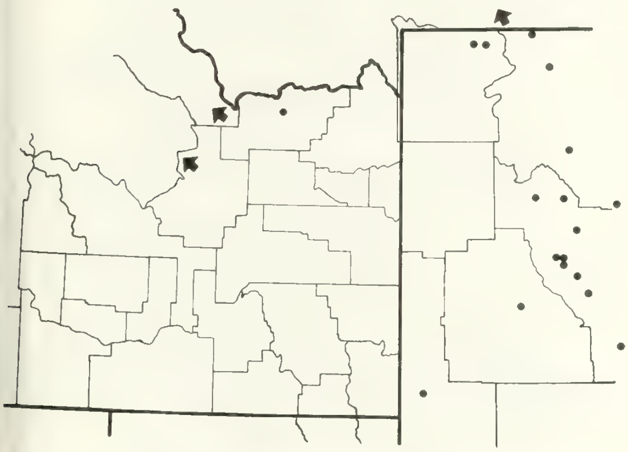
Figure 9.—*Pseudotsuga menziesii/Berberis repens* h.t., *Juniperus communis* phase on a gentle south slope in the Bighorn Mountains east of Lovell, Wyo. (2 225 m, 7,300 feet). An all-age stand of *Pseudotsuga* dominates the site. *Berberis* and *Juniperus* are well represented in an otherwise depauperate undergrowth.

Figure 10.—*Pseudotsuga menziesii/Berberis repens* h.t., *Symphoricarpos oreophilus* phase on a steep southwest slope in the Deep Creek Mountains southwest of Pocatello, Idaho (2 027 m, 6,650 feet). Widely spaced *Pseudotsuga* dominate a shrub layer composed mainly of *Symphoricarpos, Berberis, Amelanchier*, and *Artemisia*.

Figure 11.—*Pseudotsuga menziesii/Berberis repens* h.t., *Berberis* phase in the Left Fork drainage just east of Montpelier, Idaho (2 103 m, 6,900 feet). A pure stand of *Pseudotsuga* dominates this north slope. *Berberis* and *Pachistima* appear throughout the undergrowth. *Arnica cordifolia* is the dominant forb.

Other Studies.—This h.t. was first described in the southern Sawtooth National Forest (Steele and others 1974 unpubl.). Since then it has been described in central Idaho (Steele and others 1981), northern Utah and adjacent Idaho (Henderson and others 1976 unpubl., 1977 unpubl.) and north-central Wyoming (Hoffman and Alexander 1976).

Pseudotsuga menziesii/Juniperus communis h.t. (*PSME/JUCO;* Douglas-fir/common juniper)



Distribution.—*PSME/JUCO* occupies extensive areas on the east slope of the Wind River and Absaroka Ranges. It is also common in east-central Idaho and adjacent Montana. In our study area this h.t. ranges from about 1 981 to 2 835 m (6,500 to 9,300 feet) and normally occupies exposed rocky slopes at low to mid-elevations of the forest zone.

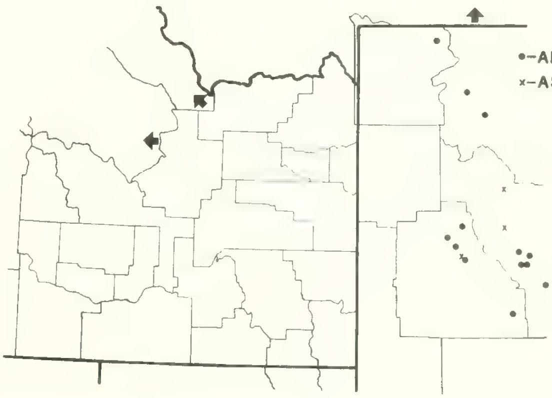
Vegetation.—*Pinus flexilis* and occasionally *P. contorta* are common seral species but they seldom dominate the site. Normally, *Pseudotsuga* dominates both seral and old-growth stands. *Juniperus communis* usually forms large patches in unburned undergrowths of older stands (fig. 12). *Symphoricarpos oreophilus* is often present and *Shepherdia canadensis* usually occurs in younger stands. *Arnica cordifolia* or *Astragalus miser* usually dominates the forb layer.

Soils.—Soil parent materials were mainly limestone or sandstone but also included shale, quartzite, granitics, and volcanics. The pH ranged from 5.6 to 7.4 and averaged 6.6. High coverages of bare rock were common and reached 50 percent. Areas of bare soil were normally less than 1 percent. Average litter depth seldom exceeded 6 cm (2.4 in.).

Productivity/Management.—Timber productivity potential is low (appendix E-2). When present, *Pinus contorta* may be near its warm, dry limits and may not respond well to management. Regeneration of *Pseudotsuga* can be sporadic and any timber harvest should be guided by the patterns of regeneration observed in the stand. Most of these sites have little potential for livestock but often receive summer use by big game.

Other Studies.—The *PSME/JUCO* h.t. was previously described in east-central Idaho (Steele and others 1981) and in Montana (Pfister and others 1977). It has not been noted in other studies of adjacent areas.

Pseudotsuga menziesii/Arnica cordifolia h.t. (*PSME/ARCO;* Douglas-fir/heartleaf arnica)



Distribution.—This major h.t. occurs mainly in the Wind River Range and the east flank of the Absaroka Range. It is also common in east-central Idaho and adjacent Montana. In our area it ranges from about 2 103 to 2 896 m (6,900 to 9,500 feet) and occupies a variety of dry aspects at low to mid-elevations of the forest zone.

Vegetation.—Usually *Pseudotsuga* and small amounts of *Pinus flexilis* are the only trees present but *Pinus contorta* or *Juniperus scopulorum* may appear on some sites. *Symphoricarpos oreophilus, Poa nervosa*, and *Festuca idahoensis* are common members of a generally depauperate undergrowth. *Arnica cordifolia* or *Astragalus miser* are the dominant forbs and indicate phasal differences as noted below.

Astragalus miser (*ASMI*) phase.—This phase occurs locally from about 2 499 to 2 896 m (8,200 to 9,500 feet) in the Wind River Mountains. It also occurs in the Lemhi and Beaverhead Ranges of east-central Idaho. *Pinus flexilis* is usually present and *Astragalus miser* dominates the undergrowth. The forb layer here is usually even more depauperate than in the *ARCO* phase.

Arnica cordifolia (*ARCO*) phase.—The *ARCO* phase occurs from 2 103 to 2 789 m (6,900 to 9,150 feet) and is widespread geographically. This phase occasionally supports *Pinus contorta*, otherwise *P. flexilis* and *Pseudotsuga* are the only trees present. Sometimes *Astragalus miser* will codominate with the *Arnica* and may denote areas transitional to the *ASMI* phase.

Soils.—Soil parent materials were mainly sandstone or limestone but also included granitics, gneiss, and volcanics. The pH ranged from 4.9 to 7.5 and averaged 6.6. Coverages of bare rock varied but were usually less than 3

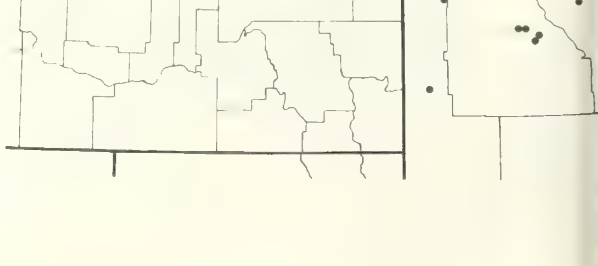
Figure 12.—*Pseudotsuga menziesii/Juniperus communis* h.t. in the West Branch Hams Fork drainage due east of Border, Wyo. (2 560 m, 8,400 feet). This southern outlier of the h.t. occurs on a steep westerly slope and is dominated by an exceptionally open stand of *Pseudotsuga*. Large patches of *Juniperus communis* dominate the undergrowth.

percent. Areas of bare soil were usually less than 1 percent. Average litter depths on a site seldom exceeded 4 cm (1.6 in).

Productivity/Management.—Tree regeneration is often infrequent and spotty and may not improve with management on these dry sites. Some seral stands in early pole-sized stages may appear overstocked, especially in the *ARCO* phase, but tree growth potential is low (appendix E-2). Early seral stands provide some forage for domestic livestock; animals attracted to these sites may damage tree seedlings. More mature stands offer little forage but provide shelter for animals that feed in nearby grasslands. In some areas these stands also provide important cover for deer and elk.

Other Studies.—The *PSME/ARCO* h.t. was previously described in central Idaho (Steele and others 1981) and Montana (Pfister and others 1977).

Pseudotsuga menziesii/Symphoricarpos oreophilus h.t. (*PSME/SYOR*; Douglas-fir/mountain snowberry)



stribution.—*PSME/SYOR* is a minor h.t. that occurs ainly in the Wind River Range and in east-central Idaho. occurs from about 2 012 to 2 530 m (6,600 to 8,300 feet) d typically represents a lower timberline condition ere the timberline is relatively high. It can occupy a riety of slopes and aspects but southerly aspects are st common.

getation.–Occasionally *Pinus flexilis* or *Juniperus opulorum* are present but usually *Pseudotsuga* is the ly tree on the site. The trees are usually widely spaced. *mphoricarpos oreophilus* normally dominates a shrub er that includes *Artemisia tridentata* and *Ribes cereum*. nerally forbs are sparse and *Agropyron spicatum* minates the shrub interspaces. Adjacent drier sites ually support steppe or mountain shrub communities minated by *Symphoricarpos oreophilus, Artemisia tri-ntata*, and *Festuca idahoensis*. The *PSME/ARCO* or *MEIJUCO* h.t.s are most common on adjacent moist es.

ils.—Soil parent materials included calcareous shale, ndstone, granitics and limestone. The pH ranged from to 7.6 and averaged 6.4. Coverage of bare rock varied nsiderably and reached 40 percent. Areas of bare soil ched 5 percent. Average litter depth on a site seldom ceeded 5 cm (2 in).

oductivity/Management.—Timber productivity is low to y low (appendix E-2) and trees regenerate sporadically this h.t. Success at artificial regeneration is apt to be v since these sites have inherent stockability limita-ns. The abundant shrubs and grasses attract both wild d domestic herbivores and the trees can shelter animals t use adjacent rangelands.

her Studies.—The *PSME/SYOR* h.t. was previously de-ribed in central Idaho (Steele and others 1981) and its esence is noted in Montana (Pfister and others 1977). ed (1969) described a *PSME/SYOR* h.t. in Wyoming that s much broader and included our *PSME/ARCO* h.t. and mall amount of the *PSME/BERE* and *PIFL/HEKI* h.t.'s.

eudotsuga menziesii/Festuca idahoensis h.t. (*SME/FEID*; Douglas-fir/Idaho fescue)

stribution.—*PSME/FEID* is an incidental h.t. in the study a. It was found in small amounts along the North Fork the Shoshone River where it occupies northerly aspects about 1 829 m (6 000 feet). It represents a lower timber-li condition and borders *Artemisia tridentata/Festuca hoensis* communities.

getation.—Open stands of *Pseudotsuga* dominate the s. *Symphoricarpos oreophilus* and *Ribes cereum* are srse but occur throughout the stand. *Festuca idahoen-s* dominates the undergrowth and is often accompanied b *Elymus cinereus* and *Hesperochloa kingii*.

ductivity/Management.—Timber productivity typically is k to very low and tree regeneration is sporadic. In some as forage values exceed those of timber and the sites a often important big game winter range.

Other Studies.—*PSME/FEID* is more common in Montana (Pfister and others 1977) and in central Idaho (Steele and others 1981). Both of these studies describe the *Festuca idahoensis* phase, which is the only phase known from our study area.

Picea engelmannii Series

Distribution.—As more areas of the Intermountain West are ecologically inventoried, the community ecology and distribution pattern of *Picea engelmannii* appears increasingly complex. Its status in northwestern Montana and northern Idaho is generally that of a minor seral component of the *Abies grandis, Thuja*, and *Tsuga* series. Beyond the eastern range of these three, *P. engelmannii* is of minor to moderate seral importance in the *Abies lasiocarpa* series. In our study area, as in Montana (Pfister and others 1977) and central Idaho (Steele and others 1981), *P. engelmannii* occurs as a climax codominant or dominant on the wettest habitat types, where it appears more successful than *A. lasiocarpa*. The importance of *P. engelmannii* generally increases and that of *Abies lasiocarpa* decreases, progressing away from the Pacific maritime influence. This increase in *Picea* importance becomes conspicuous in the highest elevation forests along the eastern periphery of the study area where most frequently *Picea*, rather than *Abies*, joins *Pinus albicaulis* as a codominant on the more severe sites. The relative abundance of *Picea* to *Abies* spp. with increasing elevation is most strongly expressed in the Southwest; this trend has been described in Colorado (Wardle 1968; Pearson 1931) and New Mexico and Arizona (Pearson 1931; Moir and Ludwig 1979; Layser and Schubert 1979). In parts of the study area, *Picea* also surpasses the lower limits of *Abies* and either interfingers with the *Pseudotsuga* series or forms the lower timberline.

Hybridization of *P. glauca* and *P. engelmannii* is widespread across Montana and extends into northeastern Yellowstone National Park and southward in the Absaroka Range. Pfister and others (1977) and Daubenmire (1974) have hypothesized that through hybridization introgression of *P. glauca* genes into *P. engelmannii* populations has allowed *Picea* to extend downslope below the limits of *A. lasiocarpa*. Such an extension for *P. engelmannii* x *P. glauca* was noted within the study area on calcareous parent materials.

Hybridization of *P. pungens* and *P. engelmannii* has been suggested (Porter 1957; Weber 1976) but Daubenmire (1972) analyzed *Picea* populations over a wide range and presented evidence that this speculation is unfounded. A more detailed study in the Colorado Front Range (Mitton and Andalora 1981) also found no hybrids. *Picea pungens* occurs in the study area at the lower forested elevations along the Hoback, Snake, and Buffalo Fork Rivers and on the western flank of the Wind River Range. It occurs mainly as a component of minor riparian types mixed with *Populus* spp., but occasionally scattered individuals appear on moist uplands. *P. pungens* can also occur as the overstory dominant of small wet areas. In the central Rocky Mountains and in the Southwest, a number of *P. pungens* habitat types have been classified (Henderson

and others 1977, unpubl.; Moir and Ludwig 1979) on both upland and riparian situations. No *P. pungens* habitat types could be recognized in our study area. Where *P. pungens* and *P. engelmannii* grow on the same site, *P. pungens* appears seral to *P. engelmannii*.

East of the Continental Divide there are large areas where *Abies* is absent and its place taken by *Picea engelmannii* or *Pinus contorta*. A strong *Picea* component was also noted on the east slope of the Salt River Range. Some of these occurrences of pure *Picea* populations might be explained by the presence of calcareous substrates, on which *Picea* can readily establish and *A. lasiocarpa* and *P. contorta* rarely occur. Other *Picea* populations in the absence of *Abies* occur as pockets, but sometimes extend hundreds of acres on Absaroka volcanics (primarily andesite) and Wind River granitics. In the Owl Creek Range, where intensive sampling was conducted, the northwestern portion supports virtually no *Abies*; all sites more moist than the *Pseudotsuga* series and warmer or moister than the *Pinus albicaulis* series belong in the *Picea engelmannii* series. Farther to the southeast in the Owl Creek Range (farther from a maritime climate) on comparable substrates, *Abies* codominates with *Picea*. This pattern is an apparent local contradiction to the usually inferred affinity of *Abies* for more maritime regimes (Pfister and others 1977).

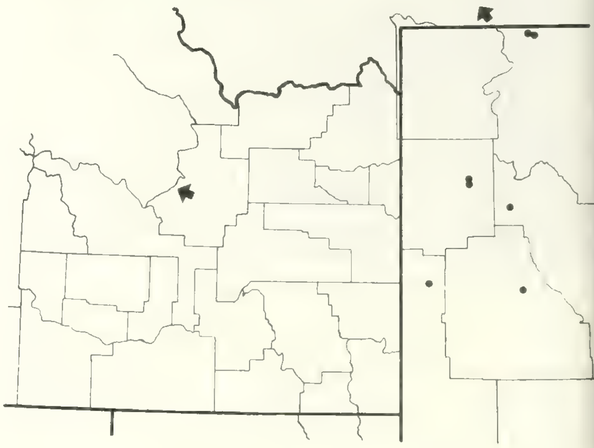
Vegetation.—Seral stand composition is dependent on habitat type and parent material. On the wettest sites, *Picea* is often the sole dominant even though *Abies* may establish on elevated microsites. *Pinus contorta* and *Pseudotsuga* are important seral components on moist to well-drained sites. *P. contorta* apparently does not grow on calcareous substrates (in the absence of high precipitation and moist microsites), but *Pseudotsuga* often grows well on these sites. *Populus tremuloides* is relatively uncommon in the *PIEN* series and, for the study area as a whole, pure or mixed stands of *P. tremuloides* are most limited where *PIEN* habitat types are the most extensive. On the driest sites, *Pinus flexilis* is usually a minor seral component of *PIEN* habitat types but may be locally important on calcareous substrates where its upper elevational range is much extended. On dry sites at high elevations, *P. albicaulis* can become the major seral species on noncalcareous substrates.

The undergrowths in this series vary such that habitat types representing the two ends of the moisture continuum have virtually no species in common except *Picea*. Many undergrowths strongly resemble similar habitat types of the *Abies* and *Pseudotsuga* series. In some instances the only floristic difference between habitat types is the inferred climax-dominant tree species.

Fire.—Much of this series shows little evidence of fire, which is partly due to the high proportion of wet to moist habitat types. The high-elevation types (*PIEN/VASC, PIEN/HYRE*) are also less frequently burned than lower elevation sites because they occur as relatively small, often discontinuous areas, with low fuel loadings. The low-elevation types, *PIEN/ARCO* and *PIEN/JUCO*, have th greatest occurrence of seral tree species and generally have the highest fire frequencies within the series.

Productivity/Management.—In Wyoming, the *Picea engelmannii* series apparently spans a wider spectrum o sites, especially dry sites, than in Montana or Idaho. These sites span a wide elevation range from low elevation stream bottoms to upper timberline. Both the wettes and driest types represent extreme environmental conditions, which are reflected in the low yield capabilities of these sites (appendix E-2). Many of the high-elevation sites are of marginal productivity and still inaccessible enough to preclude timber harvest. Some sites with high water tables are relatively productive but are easily degraded by timber harvesting. The wet to moist types constitute important habitat for moose, elk, deer, and bear.

Picea engelmannii/Equisetum arvense h.t. (*PIEN/EQAR*; spruce/common horsetail)



Distribution.—*PIEN/EQAR* is a minor h.t. that occurs sporadically in small patches from the Greys River and Wind River Range northward into Montana and east-central Idaho. It ranges from 1 890 to 2 652 m (6,200 to 8,700 feet) and occupies the saturated soils of stream terraces, benches, or seeps (fig. 13). This h.t. was most frequently noted to border *PIEN/GATR, ABLA/STAM* or *ABLA/VAGL* h.t.'s on upland sites with a relatively sharp ecotone between types.

Vegetation.—*Picea engelmannii* is usually the dominant tree of any successional stage on these sites, but one low-elevation site was dominated by *P. pungens*. *Pinus contorta* is a minor seral species, and small numbers of *Abies lasiocarpa* often appear in the stand but are usually restricted to raised microsites. The *PIEN/EQAR* sites in our study differ from those in Montana in that they are generally above the elevational limits of *Populus trichocarpa* and *P. angustifolia* and south of the distributional limits of *Betula papyrifera*.

igure 13.—*Picea engelmannii/Equisetum arvensis* h.t. on a broad stream terrace in ie southern end of the Beartooth Mountains (2 130 m, 6,986 feet). Old *Pinus contorta* ıd all-age *Picea* dominate the site. The abundance of *Equisetum* indicates a ıbstrate that is wet much of the year.

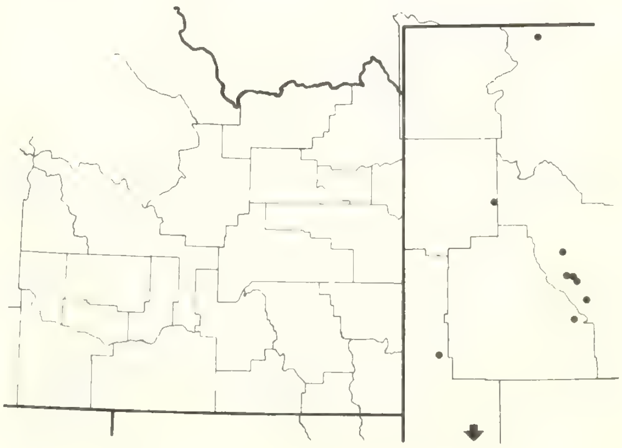
ıe undergrowth is dominated by *Equisetum arvense* and ·ich assortment of wet site forbs, such as *Streptopus ıplexifolius, Parnassia fimbriata*, and *Senecio trian- ılaris*, and the graminoids *Carex* spp., *Juncus* spp. and *ızula parviflora*. The shrub component is relatively ·pauperate. The sometimes extreme micro-relief gener- ıed by root crown hummocks and windthrow mounds ac- ıunts for the high species richness.

ɔils.—Owing to the topographic position of these sites, ɔils were largely alluvial, with a mixture of parent ıaterials. Most sites had a layer of mor humus, in some ıses to 28 cm (11 in) thick. The pH averaged 7.1 and ıged from 6.9 to 7.2.

oductivity/Management.—Timber productivity is ɔderate (appendix E-2) but of little consequence be- ıuse of the fragility of these ecosystems. The trees are ıtremely susceptible to windthrow and soil loss may ı low all forms of timber harvesting. Even if logged when ıe ground is frozen to reduce equipment impacts, evi- ınce indicates that water tables will rise, creating addi- ınal problems in site management. In some areas, ıoose, elk, and bear use these sites for feed and wallows.

Other Studies.—Cooper (1975) previously described this h.t. in part of the study area. It has also been described for Montana (Pfister and others 1977) and central Idaho (Steele and others 1981).

Picea engelmannii/Caltha leptosepala h.t. (*PIEN/CALE*; spruce/marsh marigold)



Distribution.—This minor h.t. occurs mainly east of the Continental Divide from the Beartooth and Absaroka Ranges southward to the Wind River Range. It also occurs in the Bighorn Mountains of Wyoming and the Uinta Range of Utah. *PIEN/CALE* occupies limited areas along streambanks and terraces and ranges from about 2 499 to 2 896 m (8,200 to 9,500 feet). It often forms an abrupt ecotone with *PIEN/VASC* or *ABLA/VASC* h.t.'s.

Vegetation.—*Picea engelmannii* dominates both seral and climax communities. *Pinus contorta* and *P. albicaulis* are minor seral components. *Abies lasiocarpa* may achieve co-dominant status predominantly on raised microsites, but the specimens seldom outcompete *Picea*.

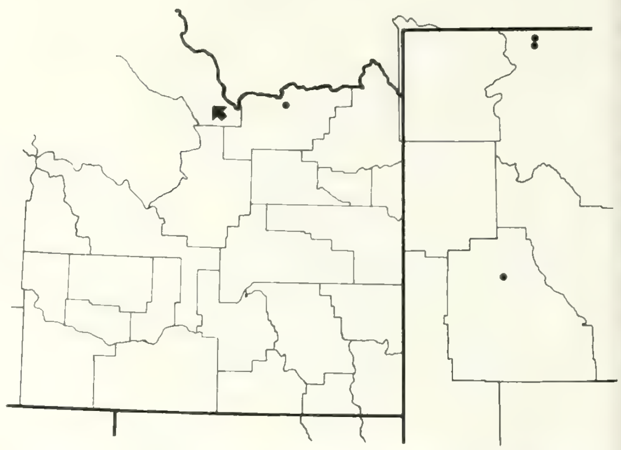
The undergrowth is characterized by either of the diagnostic species, *Trollius laxus* or *Caltha leptosepala*, and a rich complement of wet-site forbs such as *Mitella pentandra, Senecio triangularis, Saxifraga arguta, Veronica* spp. and *Parnassia fimbriata. Carex* spp., *Juncus* spp., *Calamagrostis canadensis*, and *Luzula parviflora* are the graminoids of highest constancy but normally they have low coverages. As in the *PIEN/EQAR* h.t., the shrub layer is relatively simple, but *Vaccinium scoparium* occasionally achieves high coverages on hummocks. Other ericaceous dwarf shrubs typical of bog sites, such as *Kalmia polifolia, Phyllodoce empetriformis*, and *Vaccinium occidentale* attain modest coverages.

Soils.—Parent materials were all noncalcareous and were primarily granitic alluvium. In rare instances sites were found on limestone-sandstone contact zones. The alluvial nature of these soils is reflected in the low coarse-fraction content, which averaged 11 percent. Soils are nearly perpetually saturated; only the raised microsites dry to any degree. Most sites have a deep deposit of organic muck and are characterized by gleization of lower horizons and moderately acidic pH values (5.3 to 6.1, average of 5.7).

Productivity/Management.—Timber productivity is very low to moderate, (appendix E-2). This productivity range is the lowest of the moist to wet h.t.'s., possibly because *PIEN/CALE* occurs at relatively high elevations (colder sites). Because there are no major seral trees, these sites can be expected to produce mostly *Picea* and lesser amounts of *Pinus contorta*. Sites logged in the Wind River Range more than 50 years ago reverted to swamps dominated by ericaceous shrubs and *Salix* spp. *Picea* and *Pinus contorta* were slow to reestablish. Though these early seral sites appear to offer excellent forage, little evidence of livestock use was noted; however, elk and moose may use these sites considerably during the summer. Road construction and site preparation are extremely difficult because of high water tables. If the site is logged, all trees of a given height should be harvested to prevent loss to windthrow of the residual stems projecting above the main canopy height.

Other Studies.—Henderson and others (1977 unpubl.) describe this h.t. in the Uinta Mountains of Utah. A similar *Abies lasiocarpa/Caltha biflora* h.t. occurs in central Idaho (Steele and others 1981).

Picea engelmannii/Carex disperma h.t. (*PIEN/CADI*; spruce/softleaved sedge)



Distribution.—This minor h.t. occurs mainly in east-central Idaho and extends sporadically eastward into the Centennial Mountains. It also occurs locally in the Beartooth, Absaroka, and Wind River Ranges. *PIEN/CADI* occurs from about 2 195 to 2 408 m (7,200 to 7,900 feet) and usually occupies stream terraces near the lower limits of *Abies lasiocarpa*.

Vegetation.—Although one may expect to find *Pinus contorta* as a seral dominant on these sites it was not found as such in the study area. Usually, *Picea engelmannii* is the dominant tree (one stand in the Wind River Range was dominated by *Picea pungens*). Occasionally a few *Abies lasiocarpa* appear on raised microsites. Undisturbed undergrowths, rare due to trampling by cattle, are dominated by a layer of *Carex disperma*. A diverse assemblage of wet-site forbs also occurs throughout the stand. *PIEN/CADI* appears similar to *PIEN/EQAR* and contains many of the same-wet site herbs and shrubs.

Soils.—Soils are saturated most of the year and support an organic layer that can reach at least 30 cm (11.8 in). Roots are mostly confined to this layer, which is usually considered muck. Other soils data for this h.t. are lacking.

Productivity/Management.—Timber productivity is low to moderate (appendix E-2), and tree seedlings probably require the raised microsites of hummocks and fallen logs for establishment. Partial cutting in old-growth stands may subject remaining large trees to windthrow. Machinery and livestock can easily churn the *Carex* mat and leave the substrate exposed to erosion. The livestock find little forage here but seek these cool, wet sites for resting and watering. Moose, elk, and black bear may use these sites for wallows.

Other Studies.—*PIEN/CADI* is also described in east-central Idaho (Steele and others 1981).

Picea engelmannii/Physocarpus malvaceus h.t. (*PIEN/PHMA*; spruce/ninebark)

Distribution.—This incidental h.t. was found in the Clarks Fork drainage of the Yellowstone River at about 2 195 m (7,200 feet). It occupies northerly aspects on steep to gentle slopes.

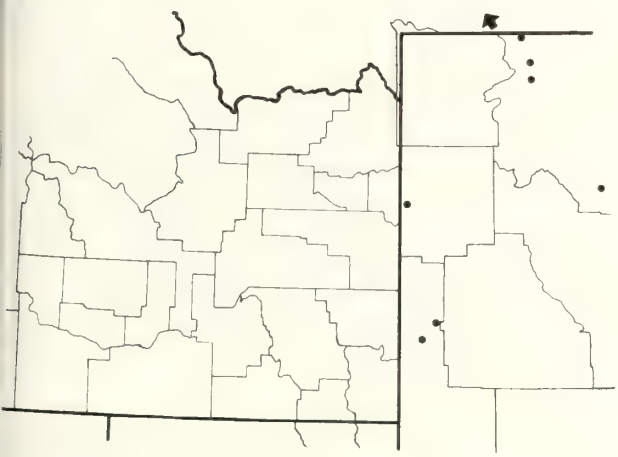
Vegetation.—In older stands, *Picea* dominates the overstory and *Pseudotsuga* is present in lesser amounts. An occasional *Abies* may be present. *Pseudotsuga* tends to dominate seral stands.

Physocarpus malvaceus dominates the undergrowth. *Galium triflorum* is a common, moist-site forb in this h.t. and is often accompanied by *Disporum trachycarpum*, and *Thalictrum* sp.

Productivity/Management.—Data from Pfister and others (1977) suggest that timber productivity is moderate. Domestic livestock appear to make little use of these sites, but deer, elk, and moose may use them for cover. Early seral stages may also provide browse for big game.

Other Studies.—Pfister and others (1977) describe *PIEN/PHMA* as an extensive h.t. in south-central Montana. It has not been noted elsewhere.

Picea engelmannii/Galium triflorum h.t. (*PIEN/GATR*; spruce/sweetscented bedstraw)



Distribution.—This minor h.t. occurs mainly in south-central Montana and extends southward into western Wyoming. Areas too small to sample were also observed in the Wind River Range. These sites typically occur on alluvial terraces or bottomlands between 1 859 to 2 499 m (6,100 and 8,200 feet). Occasionally they are associated with seeps. Adjacent sites are most frequently moist h.t.'s of the *Abies lasiocarpa* series, such as *ABLA/VAGL*, *ABLA/LIBO*, and *ABLA/VASC*.

Vegetation.—Normally *Picea engelmannii* dominates the stand, but in scattered locations in the Wind River Range and along the Greys River, *P. pungens* is sometimes dominant or codominant. Occasionally *Abies lasiocarpa* may achieve a minor foothold, and minor amounts of *Pinus contorta* and *Pseudotsuga* may invade following disturbance.

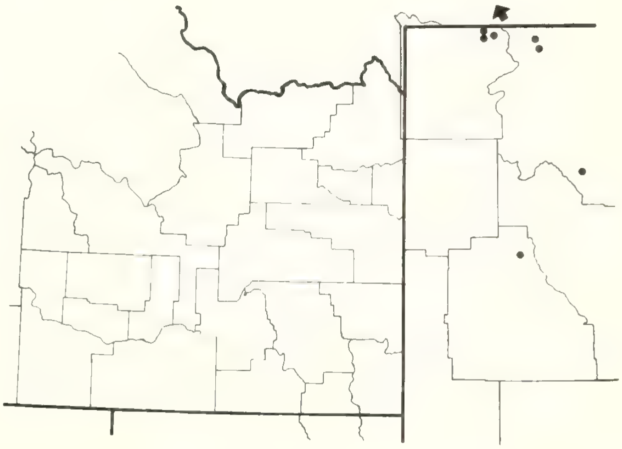
Undergrowths vary considerably as a reflection of site history and adjacent plant communities. *Galium triflorum*, *Actaea rubra*, and *Smilacina stellata* are common throughout the type. *Streptopus amplexifolius*, *Senecio triangularis*, and *Calamagrostis canadensis* may dominate the wetter microsites.

Soils.—Soils were developed chiefly on alluvial deposits of various origins, which include limestones, quartzite, sandstones, and shale. Despite the presence of high water tables most of the year, these sites display generally high pH values, which range from 6.0 to 8.1 (average 7.1). Bare soil and rock are virtually absent but the coarse fraction content is relatively high (25%). Average litter depth can reach 10 cm (3.9 in). Some sites have wet organic layers that can exceed 50 cm (20 in).

Productivity/Management.—Based on limited data, timber productivity ranges from moderate to very high (appendix E-2). *Picea* and sometimes *Pinus contorta* grow well in this h.t., but the streamside locations and high water tables may restrict timber harvest. As a result, preservation of soil and water resources may outweigh other values present. Some sites within Grand Teton and Yellowstone National Parks and the Gros Ventre Mountains were noted to sustain heavy use by moose and elk.

Other Studies.—Cooper previously described part of this h.t. as the *PICEA-ABLA/GATR* h.t. In south-central Montana, Pfister and others (1977) have recognized a *PICEA/GATR* h.t. that differs from that recognized herein only by the greater representation of *P. contorta* and *Pseudotsuga* in seral stands.

Picea engelmannii/Linnaea borealis h.t. (*PIEN/LIBO*; spruce/twinflower)



Distribution.—*PIEN/LIBO* is a minor h.t. from the Wind River Mountains northward into central Montana. Only in the northeastern portion of Yellowstone National Park and contiguous portions of the Shoshone National Forest did it attain an appreciable areal extent. It occurs primarily at moderate elevations of the subalpine zone (1 890 to 2 499 m [6,200 to 8,200 feet]) on steep slopes as well as alluvial terraces and well-drained benches that shed cold air.

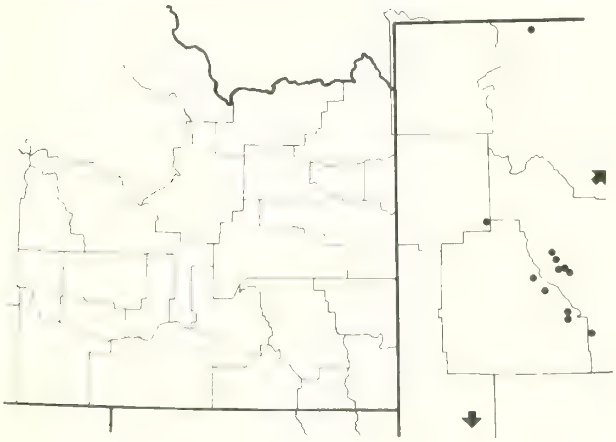
Vegetation.—*Pinus contorta* and *Pseudotsuga* are the most important seral tree species. This is the most moist of the *Picea* h.t.'s in which *Pseudotsuga* is a major seral species. *Picea engelmannii* usually codominates with the seral trees in the later successional stages. *Linnaea borealis* characterizes the undergrowth but may be overtopped by a rich assortment of shrubs, some of which typify drier sites; for example, *Juniperus communis* and *Symphoricarpos albus*.

Soils.—In the northeastern portion of the study area, this type was observed on Absaroka volcanics (chiefly andesite and rhyolite). It was also noted on limestone and granitics. Areas of bare rock and bare soil were usually less than 1 percent. Average litter depth on a site can reach 10 cm (3.9 in).

Productivity/Management.—Timber potentials range from low to high and are mostly moderate (appendix E-2). The gentle terrain generally associated with this habitat type favors intensive timber management. *Picea, Pinus contorta*, and *Pseudotsuga* should regenerate easily on these sites. Single-tree and group-selection cuts will favor *Picea*; larger openings will favor *Pseudotsuga* and *Pinus contorta*. Domestic livestock and big game seldom find much forage on these sites, but big game animals may use these areas for shelter and resting.

Other studies.—Cooper (1975) described a *Picea-Abies/Libo* complex in Yellowstone National Park that included *PIEN/LIBO*. Pfister and others (1977) described a *Picea/Libo* h.t. in Montana.

Picea engelmannii/Vaccinium scoparium h.t. (*PIEN/VASC*; spruce/grouse whortleberry)



Distribution.—In the study area, *PIEN/VASC* was found primarily in the Wind River Range, but it also appears in the Bighorn Mountains of Wyoming and in the Uinta Mountains of Utah. It represents the upper elevations of the *Picea engelmannii* series and ranges from about 2 682 to 3 292 m (8,800 to 10,800 feet). This h.t. is most common on gentle terrain but extends to steep slopes of predominantly northerly exposures. With increasing elevation, *PIEN/VASC* may grade into a *PIAL/VASC* or *PIAL/CARO* h.t. *PIEN/VASC* was conspicuously absent in the Owl Creek Range where it is replaced by *ABLA/VASC* on similar positions and substrates.

Vegetation.—*Pinus contorta* is the important seral tree species at lower elevations, with seral dominance gradually shifting to *P. albicaulis* and *Picea* at higher elevations. Both pines are only slowly replaced by the climax dominant *Picea*. *Abies* is sometimes present but shows little potential for increasing.

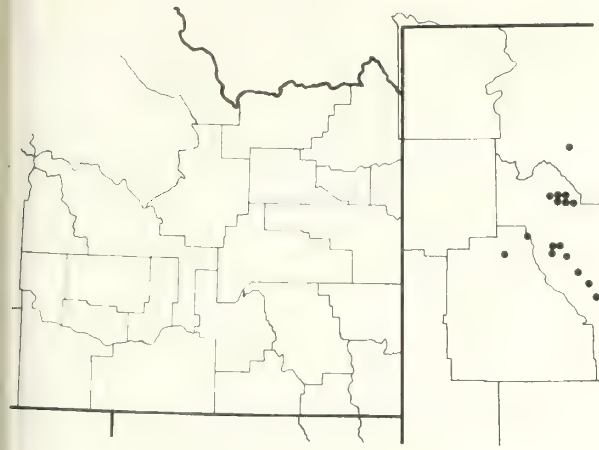
The undergrowth, dominated by *Vaccinium scoparium*, is depauperate but usually includes *Antennaria microphylla, Arnica cordifolia, Lupinus* spp., and *Solidago multiradiata*. The forbs seldom attain high coverages; *Arnica cordifolia* is usually the most prevalent.

Soils.—In the study area, this h.t. was found mainly on granitic or sandstone substrates, but in Utah it has been noted on quartzite (Henderson and others 1977 unpubl.). The pH averaged 5.2 and ranged from 4.8 to 5.5. Bare rock and bare soil did not exceed 5 percent, but granitic outcrops occasionally reached 15 percent in coverage. In several areas where *PIEN/VASC* occurred in a mosaic with drier sites, soil pits revealed a deeper A1 horizon and much greater (twofold to fourfold) depth to regolith for the *PIEN/VASC* h.t. We could not account for the differential soil depths between sites, which may have been due to past erosional patterns.

Productivity/Management.—Timber productivity is low to moderate (appendix E-2) and apparently decreases with increasing elevation. *Pinus contorta* should regenerate well in openings, but cones of many populations are nonserotinous, which may pose problems when attempting to regenerate *P. contorta* in extensive clearcuts. *Picea* regeneration is favored by single-tree and group-selection cuts, which provide protection from dessication. Domestic stock find almost no forage here, but elk and deer use these sites for cover during the summer.

Other Studies.— Reed (1969) originally described this h.t. in the Wind River Range, but he also included stands that contain successful *Abies* reproduction and therefore conform to our *ABLA/VASC* h.t. A similar approach was taken by Hess (1981) in northern Colorado. In the Bighorn Mountains, Hoffman and Alexander (1976) describe a *PIEN/VASC* h.t., part of which occurs at somewhat warmer, lower elevations and contains *Berberis repens* and *Spiraea betulifolia*. *PIEN/VASC* extends with some floristic modification to the Uinta Mountains of Utah (Pfister 1972a) and the Colorado Front Range, where some mountains support climax *Picea* with *Vaccinium myrtillus* or *V. scoparium* (Peet 1978; Marr 1961). Similar conditions also appear in New Mexico (Moir and Ludwig 1979).

'icea engelmannii/Juniperus communis h.t. PIEN/JUCO; spruce/common juniper)



)istribution.—*PIEN/JUCO* is a major h.t. in southern ortions of the Absaroka Range, the Owl Creek Mounains, and the east flank of the Wind River Range. It ocurs widely from about 2 255 to 3 139 m (7,400 to 10,300 eet) and occupies a variety of topographic positions. This ı.t. may form upper tree line at about 3 139 m (10,300 feet) n calcareous substrates. Usually it occupies cool expoures, ranging from northwest to east. *PIEN/JUCO* may order *ABLA/ARCO, PIEN/ARCO, PIFL/JUCO* or nonforest ommunities in the Absaroka and Owl Creek Ranges. In he Wind River Range, it usually borders *PSME/JUCO or 'SME/ARCO* on sedimentaries and *PIEN/VASC* or *'IAL/VASC* on granitics.

/egetation.—Tree composition of seral stands is strongly lependent upon parent material; *Pseudotsuga, Picea*, and *'inus flexilis* are the primary seral species on calcareous ubstrates. On extrusive volcanics (chiefly andesites), *P. ontorta* and *Pseudotsuga* are equally competitive and *P. lexilis* is a minor species. Sandstones (and granitics?) avor *P. contorta* as the primary seral species. *Pseudotuga* seldom occurred on granitics and only sporadically n sandstones. *P. albicaulis* was notably absent in much f the h.t..

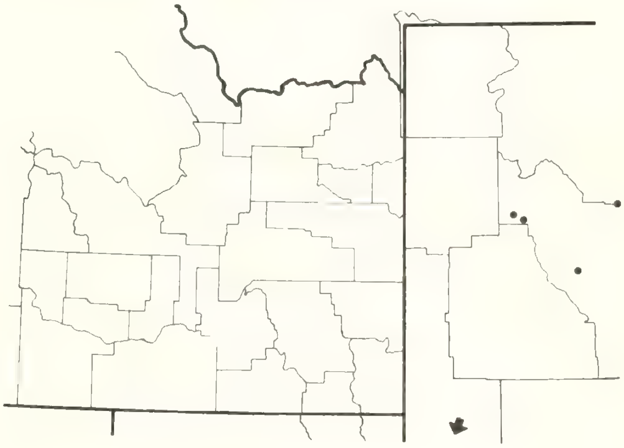
Juniperus communis gradually forms large patches that re easily destroyed by fire. *Shepherdia canadensis* is often present and in younger stands may be a dominant r codominant shrub. The forb layer is characterized by *Arnica cordifolia* and *Astragalus miser* and to a lesser legree by *Solidago multiradiata*. On calcareous substrates *Frasera speciosa* is usually present. Of the graminoids, only the virtually ubiquitous *Carex rossii* and *Poa nervosa* ave high constancies.

Soils.—Soil parent materials were primarily calcareous sedimentaries and Absaroka volcanics, but granitics were also represented. The pH ranged from 5.05 (on altered andesite) to 7.3 (on limestone) and averaged 6.4. Areas of bare soil were usually less than 1 percent. Areas of bare rock were usually less than 5 percent. Coarse fraction content, which ranged from 3 to 76 percent and averaged 26 percent, is near the high end of the spectrum for this series. Average litter depths reached 9 cm (3.5 in).

Production/Management.—Timber productivity is mostly low (appendix E-2), especially on calcareous substrates. The low potentials result from the poor site quality for commercial species and a large contribution by *Pinus flexilis* to stand basal area. Stand regeneration on calcareous substrates appears difficult to achieve. Old cuts on these sites have suffered severe erosion and are still poorly stocked after nearly 100 years since logging. Although grazing pressure may be a contributing factor in these cases, the h.t. as a whole shows little potential for rapid recovery. Forage for domestic livestock and big game species is minimal in older stands, but timber harvesting on noncalcareous soils may enhance forage production. On calcareous substrates *Lupinus* spp. and *Astragalus miser* may increase with disturbance and to some extent preclude the increase in range grasses.

Other Studies.—*PIEN/JUCO* is not described elsewhere; however, a somewhat similar *Picea/Senecio streptanthifolius* h.t. is described in Montana (Pfister and others 1977).

Picea engelmannii/Ribes montigenum h.t. (PIEN/RIMO; spruce/mountain gooseberry)



Distribution.—This minor h.t. was found on gently rolling plateaus of the Wind River Range and in the highest portions of the Owl Creek Range. It also occurs in southern Utah. Although one site occurred on a steep north slope at 2 560 m (8,400 feet), most sites range from 2 743 to 2 956 m (9,000 to 9,700 feet). This h.t. often appears as patches of timber interspersed by grassy meadows and seasonal wetlands.

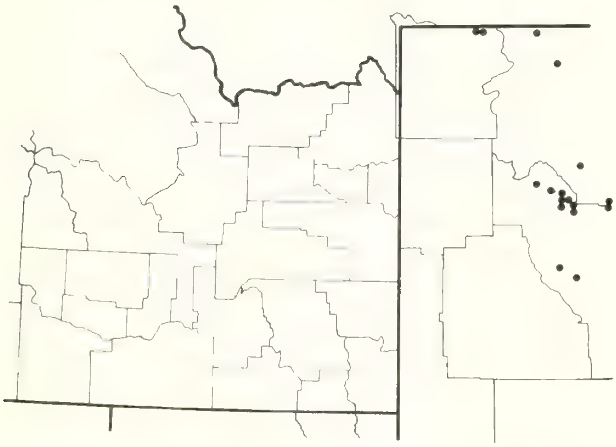
Vegetation.—In seral stands, *Picea* may be the only tree present, but on granitics it is often accompanied by *Pinus contorta* or *P. albicaulis*. On limestones and extrusive volcanics, *Picea* is strongly dominant and mixes primarily with small amounts of *Pinus flexilis*. Rarely *Abies* is present as unthrifty seedlings or saplings. Undergrowths are depauperate but usually include *Ribes montigenum* as the principal shrub. *Arnica cordifolia, Aquilegia coerulea*, and *Lupinus* spp. are the most common forbs.

Soils.—Reconnaissance data indicated that this habitat type occurs on andesite, limestone, and granitic parent materials. The pH values ranged from 4.2 on granite to 6.8 on limestone (average 6.2). Areas of bare rock and bare soil were both less than 2 percent. Average litter depth per site reached 10 cm (3.9 in).

Productivity/Management.—Timber productivity potentials are low (appendix E-2). Where present, *Pinus contorta* should regenerate when canopy openings are created. *Picea* will be favored by smaller openings. Livestock and big game usually find little forage on these sites but may use them as refuges when grazing adjacent meadows. An important function of these sites may be watershed protection and delay of run-off.

Other Studies.—In southern Utah, Pfister (1972a) described a *PIEN/RIMO* h.t. which, because of its extreme geographic separation and floristic differences, should be considered a variant of the above type. Topographic position and site descriptions of Pfister's type, however, are remarkably similar to ours. In the Medicine Bow Mountains of Wyoming, Billings (1969) described "ribbon forests" at the upper forest line that closely resemble the *PIEN/RIMO* and *ABLA/RIMO* h.t.'s.

Picea engelmannii/Arnica cordifolia h.t. (*PIEN/ARCO*; spruce/heartleaf arnica)



Distribution.—*PIEN/ARCO* is a major h.t. from the Absaroka Range southward to the Owl Creek Mountains and Wind River Range. It appears mainly on gentle northwest to easterly aspects from about 2 286 to 3 048 m (7,500 to 10,000 feet). Although *PIEN/ARCO* borders a variety of more moist h.t.'s, adjacent drier sites most often support a sage-grass community.

Vegetation.—*Pseudotsuga* or *Pinus contorta* is the major seral tree, depending on substrate. On calcareous substrates, *Pseudotsuga* with lesser amounts of *Pinus flexilis* codominate seral stands. On volcanics (mainly andesite), *Pseudotsuga* and *Pinus contorta* may be seral dominants, with small amounts of *Pinus flexilis* and *P. albicaulis*. On sandstones and possibly granitics, *Pinus contorta* with lesser amounts of *P. albicaulis* are the major seral trees. Usually *Picea* codominates with the seral trees in older stands (fig. 14). Undergrowths have the general appearance of the *PIEN/JUCO* h.t. but lack the shrub component. Of the forbs, *Arnica cordifolia* and *Astragalus miser* weakly dominate; *Senecio streptanthifolius* and *Frasera speciosa* attain high constancies but have low coverages on calcareous substrates. *Hesperochloa kingii* and *Carex rossii* also have high constancies on these sites.

Soils.—Soil parent materials range from limestone to granitics and Absaroka volcanics, which are mainly andesite. The pH ranges from 4.2 on quartzite to 7.1 on limestone and averages 5.8. Although soil surfaces are comparatively free of exposed rock and bare soil, the coarse-fraction content ranges up to 48 percent and averages 18 percent. Average litter depths can reach 8 cm (3.1 in).

Productivity/Management.—Timber productivity on these sites is moderate on volcanics to low on calcareous substrates (appendix E-2). Management implications parallel those of the *PIEN/JUCO* type. Regeneration problems on limestones appear severe. Opening stands via clearcutting may create severe microclimatic conditions that retard tree regeneration and may result in increased coverages of *Astragalus, Arnica*, and *Lupinus* spp. On volcanics and granitics, *P. contorta* may establish readily in forest clearings when a seed source is nearby. Forage production is low for big game and domestic livestock, though the sites are used as cover for deer, elk, and cattle. There is little potential for increasing forage production through timber harvesting.

Other Studies.—*PIEN/ARCO* has not been described elsewhere. A somewhat similar *Picea/Senecio streptanthifolius* h.t. that occurs only on calcareous substrates is described in Montana (Pfister and others 1977).

Picea engelmannii/Hypnum revolutum h.t. (*PIEN/HYRE*; spruce/hypnum)

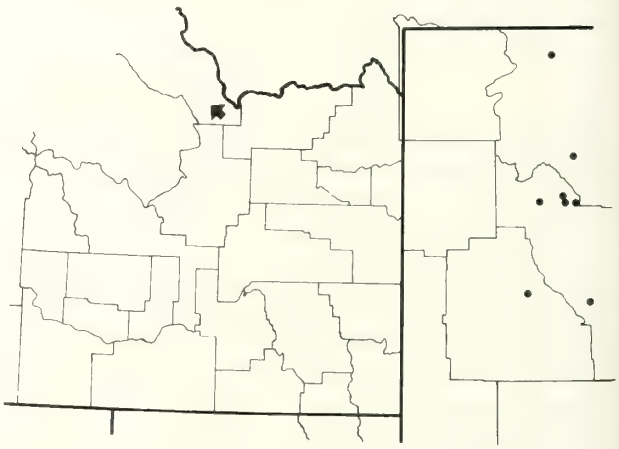


Figure 14.—*Picea engelmannii/Arnica cordifolia* h.t. on a gentle east slope in the Absaroka Range northwest of Cody, Wyo. (2 286 m, 7,500 feet). An all-age stand of *Picea* is replacing old *Pinus contorta*. An occasional *Pseudotsuga* and *Abies* are also present. *Arnica* dominates a depauperate undergrowth.

Distribution.—This minor h.t. occurs in the Owl Creek, southern Absaroka, and Wind River Ranges of Wyoming and also appears in the Lemhi and Beaverhead Ranges of east-central Idaho. It is found from about 2 347 to 3 200 m (7,700 to 10,500 feet) but appears restricted to steep northerly aspects where snow accumulates and persists into the growing season. This h.t. usually borders open meadows or *Festuca idahoensis* dominated grasslands on drier exposures or rockier soils. Downslope it merges with *PIEN/ARCO* and *PIEN/JUCO* in the Absaroka and Owl Creek Ranges and with the *Abies lasiocarpa* series in the Wind River Range.

Vegetation.—At lower elevations of the h.t., *Pseudotsuga* predominates in most stands with lesser amounts of *Picea* and *Pinus flexilis* occurring throughout. In old-growth stands, regeneration of *Picea* and *Pseudotsuga* is often equal. At the higher elevations, *Pseudotsuga* becomes scarce leaving *Picea* and occasionally some *Pinus albicaulis* to dominate the site.

Shrubs are very sparse and, if present, usually include *Shepherdia canadensis, Symphoricarpos oreophilus*, or *Juniperus communis*. A few forbs or grasses may be present in small amounts; of these, *Pyrola secunda, Arnica cordifolia*, and *Poa nervosa* are most common. Unless disturbed, a thin layer of moss, *Hypnum revolutum*, dominates the undergrowth (fig. 15). Other mosses may be scarce but *Dicranowiesia crispula* is usually present on rotting wood. *Peltigera rufescens*, a foliose lichen, is usually evident throughout the stand and *Cladonia fimbriata* is usually the common lichen on rotting wood.

Soils.—Soil parent materials were primarily Absaroka volcanics (rhyolite and andesite) but also included some limestone and granitics. Soil pH ranged from 5.3 on granitics to 7.9 on limestone and averaged 6.1. Coverages of bare rock reached 25 percent but were usually less than 5 percent. Coarse fraction content was also high and averaged 36 percent. Areas of bare soil were mostly less than 1 percent. Average litter depth per site reached 13 cm (5.1 in) but was mostly less than 7 cm (2.8 in).

Productivity/Management.—Timber productivity potential is low to very low, especially for the higher elevation stands (appendix E-2). Diameter increments for both *Picea* and *Pseudotsuga* decline rapidly at a relatively early age. Considering the steep slopes and low potential productivities for timber and forage, the greatest resource values of this h.t. may be for water yields and big game cover.

Figure 15.—*Picea engelmannii/Hypnum revolutum* h.t. on a northwest aspect in the Mud Creek drainage of the Owl Creek Mountains (3 030 m, 9,940 feet). A pure stand of *Picea engelmannii* dominates this moderately steep slope. In the undergrowth, vascular plants are virtually nil and the prostrate moss, *Hypnum revolutum*, is abundant.

Other Studies.—This habitat type is also described in the southern half of the Lemhi and Beaverhead Ranges of east-central Idaho (Steele and others 1981). A *Picea engelmannii*/moss h.t. is reported for Arizona and New Mexico (Moir and Ludwig 1979), but the vascular undergrowth is quite different and the cryptogams are not identified.

Abies Lasiocarpa Series

Distribution.—The *Abies lasiocarpa* series is the most extensive forest series in the study area. It is common in all major mountain ranges except along the eastern flank of the Absaroka Range, the Owl Creek Range, and southern portions of the Wind River Range. Typically, it borders the *Pseudotsuga* series at its lower limits and alpine communities or grassy balds at its upper limits. In some areas, its upper limits border the *Pinus albicaulis* series. On the crest of the Wind River Range, the *Abies lasiocarpa* series sometimes gives way to pure *Picea engelmannii* communities.

Vegetation.—*Pinus contorta* is the major seral tree throughout most of this series. Its successional role varies, however, from an early successional species in relatively moderate environments to one that reproduces and persists as a dominant for many decades on very severe sites. Seral *Pseudotsuga* also occurs throughout much of the series but is a major dominant in only the warmer portions where *Pinus contorta* is less abundant. *Picea engelmannii* appears throughout most of the series and becomes codominant on increasingly wetter sites. On eastern slopes of the Absaroka, Wind River, and Owl Creek Ranges, *Picea* also becomes codominant near the dry extreme of this series. *Populus tremuloides* commonly persists on the fringes of *Abies lasiocarpa* communities and as small unthrifty trees within the stand. In these situations the *Populus* may readily dominate disturbed sites by sprouting from existing root systems and may become a major seral species in various parts of the series. Although field observation suggests a ubiquity of *Populus*, our data show little or no occurrence in h.t.'s or phases

with undergrowths dominated by *Vaccinium scoparium*. Undergrowths in the *Abies lasiocarpa* series vary considerably and include dense, tall shrub layers; lush, moist-site forb layers; depauperate layers of dry-site forbs, and open grassy layers.

Soils.—Soil parent materials varied from granitics and volcanics to sedimentaries. Although h.t.'s and parent materials showed little overall correlation, the most common parent material in this series was sandstone. Some local exceptions occurred in the southeastern portion of the study area where *Abies* was notably absent on calcareous material. Other soil characteristics are best described at the h.t. level.

Fire.—Fires have altered most vegetation in this series and have created many of the *Populus tremuloides* and *Pinus contorta* stands that are found here. Many of these stands are initially fire resistant, but as they mature, susceptibility to insects and disease increases. Dead material resulting from these attacks increases the available fuel and the susceptibility to fire damage.

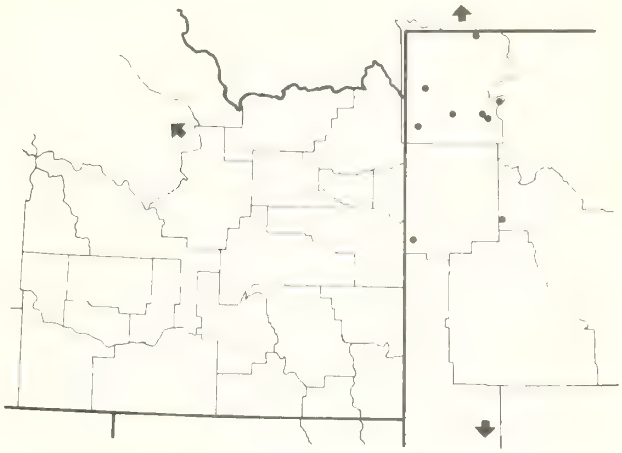
Undergrowths can also change after a fire, and form a layer characteristic of fire history. At lower elevations, *Calamagrostis rubescens* may persist under near climax conditions and then increase substantially when fire removes the competition. *Shepherdia canadensis* apparently increases following burning and may dominate the undergrowth beneath *Pinus contorta* and *Populus tremuloides*. *Shepherdia* then declines as the canopies of *Picea* and *Abies* increase and create denser shade.

Productivity/Management.—The low-elevation sites in this series are usually the most productive. Here *Pseudotsuga* may be the most productive timber species, but regeneration may be difficult. *Pinus contorta* responds better to silvicultural treatments and is fairly productive throughout much of this series. *Picea* also grows well on many sites but is prone to windthrow in partially cut stands, especially where water tables are high.

On some low-elevation sites where big game browse is in a seral condition and is fairly productive, big game has had a significant impact on secondary succession. Overwintering moose have browsed young *Abies lasiocarpa* to the point that succession is retarded and some stands superficially appear as *Pseudotsuga* or *Picea* climax. Only close examination of these stands will reveal the remnants of *Abies* as the indicated climax species. In other stands many woody plants have been reduced by browsing. In these situations, the greatest impact has been on major seral species such as *Amelanchier, Prunus*, and *Populus tremuloides*. Reduction of only the seral species hastens succession toward climax with less suitable food available for big game. In this case, logging or burning the stand may renew production of the browse species.

The high-elevation sites in this series generally have low timber potential and are used mainly for recreation, wildlife, and snowpack management.

Abies lasiocarpa/Calamagrostis canadensis h.t. (*ABLA/CACA*; subalpine fir/bluejoint)



Distribution.—This minor h.t. was found mainly in the vicinity of Yellowstone National Park. It occurs more widely in Montana, central Idaho, and parts of Utah. *ABLA/CACA* ranges from 2 073 to 2 774 m (6,800 to 9,100 feet) and usually appears along stream terraces, pond margins, and moist toeslopes. It comprises some of the wettest sites in this series.

Vegetation.—*Pinus contorta* and *Picea engelmannii* are the major seral conifers. *Abies lasiocarpa* eventually dominates the old-growth stands. Usually *Calamagrostis canadensis* is conspicuous in the undergrowth but may codominate with different species, depending on the phases noted below. Shrubs characteristic of drier sites may grow on hummocks or at the base of trees. Wet-site forbs and various *Carex* species are common in the low spots.

Ledum glandulosum (*LEGL*) phase.—This phase is incidental to the study area but was found from 2 316 to 2 682 m (7,600 to 8,800 feet) in Yellowstone National Park. Its main distribution occurs in central Idaho (Steele and others 1981). Generally this phase indicates a cool extreme of the h.t. *Ledum glandulosum* usually dominates the undergrowth; lesser amounts of other shrubs are often present.

Vaccinium caespitosum (*VACA*) phase.—This incidental phase was observed in Yellowstone National Park. Its main occurrence lies in Montana (Pfister and others 1977) and central Idaho (Steele and others 1981). Usually it indicates a frostpocket condition. These sites are often dominated by a persistent seral stand of *Pinus contorta* with lesser amounts of *Picea* and *Abies*. *Vaccinium caespitosum* is common throughout the stand.

Calamagrostis canadensis (*CACA*) phase.—This is the typical phase in our area. It was found from 2 073 to 2 774 m (6,800 to 9,100 feet) mainly in the general vicinity of Yellowstone National Park. *Calamagrostis canadensis* often dominates the undergrowth and obscures the forb layer (fig. 16). Other features of this phase correspond to the general description of the h.t.

Figure 16.—*Abies lasiocarpa/Calamagrostis canadensis* h.t., *Calamagrostis* phase on a broad wet bench in the Wind River Range west of Dubois, Wyo. (2 774 m, 9,100 feet). Large *Picea engelmannii* dominate an understory of *Abies* and *Picea*. *Calamagrostis* dominates a diverse undergrowth of wet-site forbs and graminoids.

Productivity/Management.—Timber potentials tend to be low (appendix E-2). *Pinus contorta* may be the easiest conifer to regenerate, but *Picea* may yield more timber. Regeneration of *Abies lasiocarpa* is often sporadic and may require the raised microsites of hummocks and fallen logs. In most cases, partial cutting leaves the remaining large trees prone to windthrow. Overstory removal permits the water table to rise and allows the *Calamagrostis* and *Carex* to increase and outcompete conifer seedlings. Livestock may find considerable forage here and the adjacent streams attract many animals. But until late summer, after the site has dried somewhat, the animals can churn the wet soil and destroy plant cover as well as the conifer seedlings. In some areas, bear, elk, or moose may use these sites for wallows and forage. Seral stands can produce willows and sedges, which are sought by moose and elk. The streamside locations may attract recreationists, but these wet sites are poorly suited for roads, trails, and recreational development.

Other studies.—Cooper (1975) previously noted *ABLA/CACA* in northwestern Wyoming. This h.t. is also reported from Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and northeastern Utah (Henderson and others 1977 unpubl.).

Abies lasiocarpa/Streptopus amplexifolius h.t. (*ABLA/STAM*; subalpine fir/twisted stalk)

Distribution.—*ABLA/STAM* is an incidental h.t. in the study area. It occurs mainly in central Idaho and northeastern Utah. Usually it is found at about 2 438 m (8,000 feet) as a narrow stringer along streams and seeps. These sites appear influenced by a high water table most of the year.

Vegetation.—*Picea* usually dominates the stand as a long-lived seral species. In openings, seral undergrowths normally appear as lush tall-forb communities that usually include *Senecio triangularis*. Beneath a tree canopy, these forbs become more sparse and the shade-tolerant *Streptopus* becomes more evident. Rivulets bordered by high coverages of *Saxifraga arguta* are common.

Productivity/Management.—Timber potentials may be moderate to high, but the high water tables create serious problems for timber management. Livestock forage is often abundant in seral stands, but the animals can easily churn the wet soil with their hooves and destroy the plant cover. In some areas, these sites may provide important forage and cover for elk and moose and the wet spots make good wallows. High water tables associated with these sites may preclude development of roads, trails, and recreation facilities.

Other studies.—Steele and others (1981) described two phases of *ABLA/STAM* in central Idaho; Henderson and others (1977 unpubl.) note it in the Uinta Mountains of Utah. Only the *Streptopus amplexifolius* phase is known from our area and from Utah. In Montana, Pfister and others (1977) describe an *ABLA/CACA* h.t., *Galium triflorum* phase and *ABLA/GATR* h.t. that appear related to our *ABLA/STAM* h.t.

Abies lasiocarpa/Menziesia ferruginea h.t. (*ABLA/MEFE;* subalpine fir/menziesia)

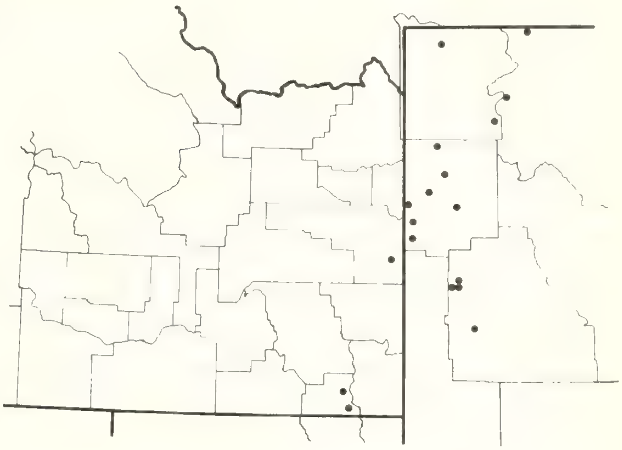
Distribution.—This incidental h.t. occurs locally on eastern slopes of the Teton Range. Here it occupies the moist ravines overlooking Jenny, Leigh, and String Lakes in Grand Teton National Park. It has also been observed in minor amounts, less than 20 acres total, on the northern portion of the Bridger-Teton National Forest (Andrew Youngblood, Bridger-Teton National Forest, pers. comm.). Its main distribution lies in northern Idaho and western Montana.

Vegetation.—Usually *Picea* is the major seral tree species. *Pinus contorta* and *Pseudotsuga* may be present in minor amounts. *Menziesia* usually dominates the undergrowth and forms a tall, dense layer.

Productivity/Management.—Data from other studies noted below suggest that timber potentials are moderate. *Picea* appears most productive and should regenerate in partially shaded openings. If *Alnus sinuata* is present, it can easily invade exposed soil in forest openings and remain dominant for many years. Domestic livestock seldom find much forage here, but big game may benefit from the dense cover and browse.

Other studies.—*ABLA/MEFE* is reported in northern Idaho (Daubenmire and Daubenmire 1968) and in western Montana (Pfister and others 1977). It also occurs in central Idaho (Steele and others 1981) where two phases exist. Only the *Menziesia ferruginea* phase is known from our area.

Abies lasiocarpa/Actaea rubra h.t. (*ABLA/ACRU;* subalpine fir/baneberry)



Distribution.—*ABLA/ACRU* is a minor h.t. from Yellowstone Park to the Idaho-Utah border. It ranges from about 2 042 to 2 499 m (6,700 to 8,200 feet). These are usually low to mid-elevations of the *Abies lasiocarpa* series. It occurs on moist but drained alluvial terraces, lower slopes, and occasionally old landslides.

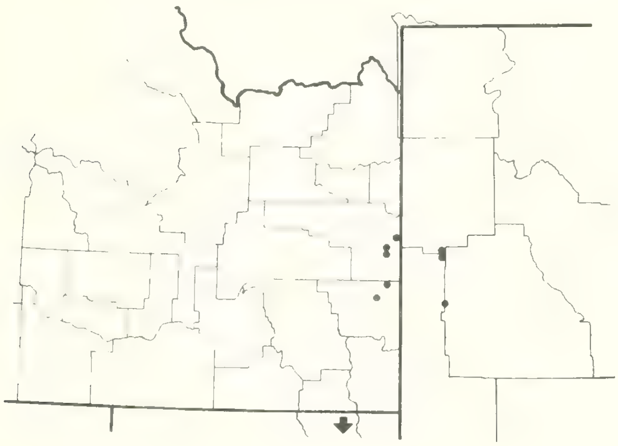
Vegetation.—*Picea engelmannii* is the major seral tree and often codominates with *Abies lasiocarpa* in old-growth stands. Lesser amounts of *Pinus contorta* and sometimes *Pseudotsuga* or *Picea pungens* may be present. Undergrowths vary somewhat but usually include *Lonicera utahensis* and *Vaccinium globulare. Rubus parviflorus* is often present on disturbed sites and *Acer glabrum* becomes prominent on sites mainly south of Alpine, Wyo. *Actaea rubra* is the characteristic species in the undergrowth and usually forms small clumps throughout the h.t. Adjacent drier sites are usually the *ABLA/VAGL* or *ABLA/ACGL* h.t. Wetter sites, if not riparian, are usually *ABLA/STAM* or *PIEN/EQAR*.

Soil.—Soil parent materials varied but were mainly of sedimentary origin. The pH ranged from 5.2 to 7.4 and averaged 6.4. Most sites had very little bare rock or bare soil. Average litter depth on a site can reach 20 cm (7.9 in).

Productivity/Management.—Timber potentials are moderate to high (appendix E-2). *Picea* regeneration appears to establish easily wherever the shrub layer is reduced, but *Abies* regeneration may be sporadic. When present, *Pinus contorta* and *Pseudotsuga* may be highly productive. Big game find considerable food and cover in the diverse assemblage of shrubs and forbs on these sites. This feature coupled with the proximity to streams results in fairly heavy use by moose. This h.t. may indicate unstable depositional soils, which can pose hazards to road and trail construction.

Other studies.—In Montana, Pfister and others (1977) describe an *Abies lasiocarpa/Galium triflorum* h.t. that appears to be related to the *ABLA/ACRU* h.t. in some respects. Cooper (1975) describes a few stands in the Teton Range as part of the Montana *ABLA/GATR* h.t. These plots are now included in the *ABLA/ACRU* h.t., which has not been described in other studies.

Abies lasiocarpa/Physocarpus malvaceus h.t. (*ABLA/PHMA;* subalpine fir/ninebark)



Distribution.—*ABLA/PHMA* is a minor h.t. that occurs from the Hoback River and near Alpine, Wyo., southward into Utah. It usually occupies fairly steep northerly aspects from about 1 829 to 2 255 m (6,000 to 7,400 feet) and represents the warm lower limits of the *Abies lasiocarpa* series in those areas.

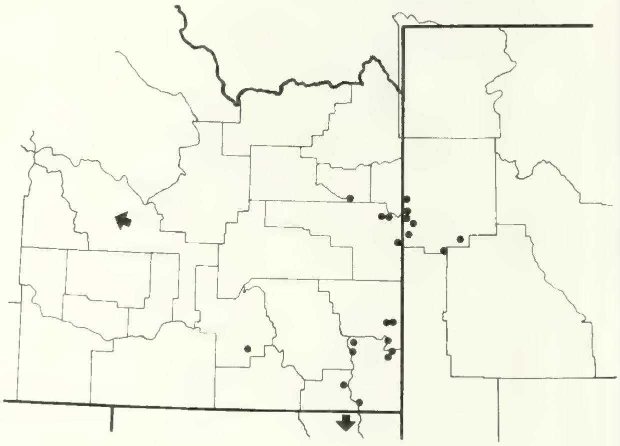
Vegetation.—*Pseudotsuga* is the major seral tree and often codominates with *Abies lasiocarpa* in old-growth stands. Lesser amounts of *Picea* are often present, but other seral conifers seldom grow here. *Physocarpus malvaceus* dominates an undergrowth that usually includes *Amelanchier, Pachistima, Spiraea, Acer glabrum*, and *Clematis columbiana*. The most common forbs are *Disporum trachycarpum, Fragaria vesca*, and *Arnica cordifolia*.

Soil.—Soil parent materials were mainly sandstone. The pH ranged from 5.7 to 7.7 and averaged 6.5. Coverage of bare rock was usually less than 3 percent and areas of bare soil were generally nil. The maximum average litter depth on a site was 8 cm (3.1 in).

Productivity/Management.—Timber productivity potential is generally moderate (appendix E-2). *Pseudotsuga* should regenerate easily wherever openings in the shrub and tree canopies coincide. *Abies lasiocarpa* appears fairly productive and should regenerate well where the shrub layer is reduced. In some areas, big game use this h.t. extensively for food and cover. Moose, especially, have depleted the *Abies*, giving some sites the appearance of a *PSME/PHMA* h.t.

Other studies.—Henderson and others (1976 unpubl.) previously described this h.t. in northern Utah and adjacent Idaho. Although no other studies have reported an *ABLA/PHMA* h.t., Pfister and others (1977) report a *PICEA/PHMA* h.t. in Montana that contains some *Abies lasiocarpa*.

Abies lasiocarpa/Acer glabrum h.t. (*ABLA/ACGL;* subalpine fir/mountain maple)



Distribution.—Most of the *ABLA/ACGL* h.t. occupies minor acreages from about the latitude of Driggs, Idaho, southward into Utah. It also occurs in central Idaho. It ranges from about 1 737 to 1 316 m (5,700 to 7,600 feet) on steep to moderate slopes having northerly aspects. This h.t. usually represents low elevations of the *Abies lasiocarpa* series. Toward its northern limits, *ABLA/ACGL* often merges with the *ABLA/VAGL* h.t.

Vegetation.—*Pseudotsuga* and *Picea* are the dominant seral trees and usually codominate with *Abies* in older stands. *Pinus contorta* is occasionally present as a minor seral species. Tall shrubs that include *Acer glabrum, Sorbus scopulina*, and in seral stands, *Amelanchier alnifolia* dominate the undergrowth (fig. 17). *Pachistima myrsinites* is usually present in a subordinant shrub layer that may include *Rubus parviflorus, Lonicera utahensis*, and *Vaccinium globulare*.

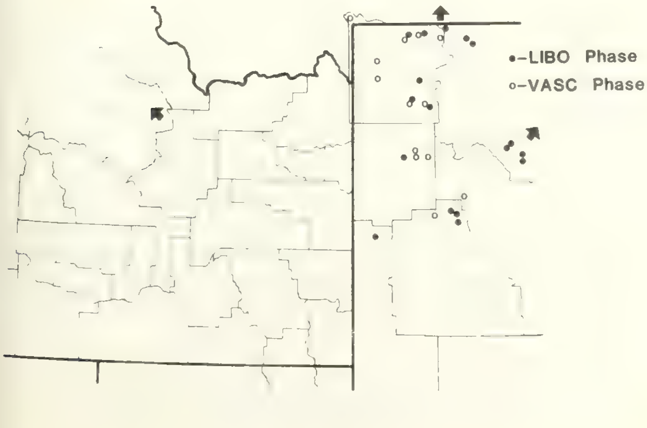
Soil.—Soil parent materials were mainly sandstone and some limestone. The pH ranged from 5.1 to 6.3 and averaged 5.7. Usually areas of bare rock or bare soil were negligible. Average litter accumulation on a site reached 8 cm (3.1 in).

Productivity/Management.—Timber potential is moderate (appendix E-2). *Pseudotsuga* is usually the most productive timber species and should regenerate easily on seedbeds of exposed soil that occur where the tree and shrub canopy is removed. Planted seedlings of *Pseudotsuga* should do well on carefully prepared sites that benefit from partial shade (Kittams and Ryker 1975). *Abies lasiocarpa* is the tree best suited for establishing beneath the shrub layer. Reducing the tree canopy should stimulate the shrub layer and provide additional forage for big game.

Figure 17.—*Abies lasiocarpa/Acer glabrum* h.t., *Pachistima* phase on a northeast slope in St. Charles Canyon, Bear River Range (2 301 m, 7,550 feet). A young stand of *Pseudotsuga* with *Abies* in the understory overtops a shrub layer composed mainly of *Acer, Sorbus, Amelanchier, Salix scouleriana*, and *Pachistima*. The forb layer is quite sparse.

Other studies.—Henderson and others (1976 unpubl.) described this h.t. in southeastern Idaho and adjacent Utah. Steele and others (1981) described *ABLA/ACGL* in central Idaho and considered it the *Acer glabrum* phase. The only phase known in the study area is the *Pachistima myrsinites* phase.

Abies lasiocarpa/Linnaea borealis h.t. (*ABLA/LIBO*; subalpine fir/twinflower)



Distribution.—*ABLA/LIBO* occurs as a minor h.t. from the Wind River Range northward through the Absaroka Range and into Montana. A few sites also occur in north-central Wyoming and central Idaho. It appears mostly on gentle slopes and benches from about 2 164 to 2 591 m (7,100 to 8,500 feet). Usually it occurs within the low to mid-elevations of the *Abies lasiocarpa* series.

Vegetation.—*Pinus contorta* and *Picea* are the major seral trees. *Picea* is more persistent, however, and often codominates with *Abies lasiocarpa* in old-growth stands. Occasionally *Pseudotsuga* is also present in seral stands. *Linnaea* is common throughout the stand even though other shrubs may create the dominant aspect. *Arnica cordifolia* is the most common forb throughout the h.t.

Vaccinium scoparium (*VASC*) phase.—This phase apparently represents a broad transition to the colder *ABLA/VASC* h.t. *Vaccinium scoparium* normally dominates the undergrowth and *Lonicera utahensis* is often present.

Linnaea borealis (*LIBO*) phase.—The *LIBO* phase appears to have a more moderate environment than the *VASC* phase; *Berberis, Shepherdia*, and *Rosa* spp. occur here more frequently. *Shepherdia* and occasionally other shrubs may increase following disturbance, but the shrubs in general are widely scattered and have thin canopies.

Soil.—Soil parent materials included basalt, andesite, granitics, quartzite, and sandstone. In the *LIBO* phase, soil pH ranged from 5.0 to 6.8 and averaged 6.0. It was slightly lower in the *VASC* phase where it ranged from 4.9 to 5.6 and averaged 5.2. In both phases, areas of bare rock or bare soil were usually less than 1 percent, and average litter depths reached 9 cm (3.5 in).

Productivity/Management.—Timber potentials are usually low to moderate (appendix E-2), but the gentle terrain often found in this h.t. can facilitate intensive timber management. *Pinus contorta* should regenerate easily on most sites having suitable openings. *Picea* and occasionally *Pseudotsuga* should regenerate well in partial shade, especially in the *LIBO* phase. *Abies* regeneration may establish slowly and sporadically.

Livestock may be attracted by the gentle terrain of these sites, which offer mostly *Calamagrostis rubescens* as forage. The animals cause little damage except for the trampling of tree seedlings.

Moose and sometimes elk use these sites extensively. The moose browse heavily on *Abies* here and often kill or deform the young trees.

Other studies.—Cooper (1975) first described this h.t. in the study area as the *Picea-Abies/Linnaea borealis* h.t. The *ABLA/LIBO* h.t. was also described in Montana (Pfister and others 1977) and in central Idaho (Steele and others 1981). A few stands recorded by Hoffman and Alexander (1976) in the Bighorn Mountains of Wyoming also conform to this h.t. The *Abies lasiocarpa/Vaccinium scoparium-Linnaea borealis* h.t. in New Mexico (Moir and Ludwig 1979) appears to be related to our *ABLA/LIBO* h.t., *VASC* phase.

Abies lasiocarpa/Xerophyllum tenax h.t. (*ABLA/XETE;* subalpine fir/beargrass)

Distribution.—This incidental h.t. occurs locally near the southern border of Yellowstone National Park. Its main distribution lies in western Montana and northern Idaho and extends southward into the northern part of central Idaho.

Vegetation.—*Pinus contorta* is a common seral dominant throughout the h.t. and, in some areas, *Picea* and *Pseudotsuga* may appear in small numbers. *Vaccinium scoparium* or *Vaccinium globulare* may be present in various amounts.

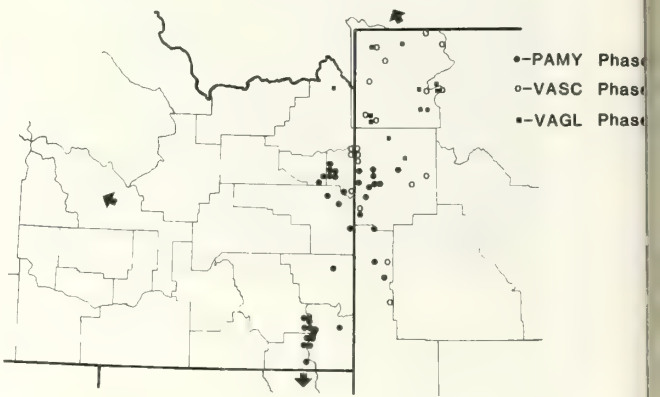
Vaccinium globulare (*VAGL*) phase.—This phase delineates the more moderate segment of the h.t. *Pseudotsuga* is more common in this phase and *Picea* often attains higher coverages. *Vaccinium globulare* usually codominates the undergrowth with *Xerophyllum*.

Vaccinium scoparium (*VASC*) phase.—The *VASC* phase marks the upper elevations of the h.t. *Pinus contorta* is the major seral tree and small amounts of *Picea* are usually present. *Vaccinium scoparium* usually dominates between the clumps of *Xerophyllum*, which are often widely spaced. *Vaccinium globulare* is usually sparse.

Productivity/Management.—Data from other studies noted below suggest that timber potentials are low to moderate. *Pinus contorta* is usually the most productive species and should regenerate well in openings that receive full sunlight. Occasionally *Picea* or *Pseudotsuga* are suitable timber species in the *VAGL* phase. Livestock find little forage here, but in summer and fall deer and elk use these sites for food and cover.

Other studies.—*ABLA/XETE* is more common in Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and northern Idaho (Daubenmire and Daubenmire 1968). Both Horton (1971 unpubl.) and Cooper (1975) have described small areas of *ABLA/XETE* in the study area.

Abies lasiocarpa/Vaccinium globulare h.t. (*ABLA/VAGL;* subalpine fir/blue huckleberry)



Distribution.—*ABLA/VAGL* occurs extensively from Yellowstone National Park southward into northern Utah. It also occurs in Montana and central Idaho. In the study area this h.t. ranges from 1 737 to 2 652 m (5,700 to 8,700 feet) and occurs mainly on northerly to easterly aspects. Generally, it represents low to mid-elevations of the *Abies lasiocarpa* series.

Vegetation.—*Pinus contorta* and *Picea* are common seral dominants throughout the h.t. and are usually mixed with younger *Abies lasiocarpa*. *Vaccinium globulare* forms a dominant layer in the undergrowth. Other features vary with phases noted below.

Vaccinium scoparium (*VASC*) phase.—This phase occurs from 2 012 to 2 591 m (6,600 to 8,500 feet) and represents the cooler segment of *ABLA/VAGL*. The low-elevation sites in this phase are usually in frost pockets. Adjacent cooler sites are usually *ABLA/VASC* h.t. *Pinus contorta* and *Picea* dominate seral stands. *Pseudotsuga* is normally absent. *Vaccinium scoparium* usually forms a notable layer beneath *V. globulare*. *Amelanchier, Pachistima*, and *Spiraea*, which are common to the other phases, are rare in the *VASC* phase.

Pachistima myrsinites (*PAMY*) phase.—This is the common phase from about the latitude of Driggs, Idaho, southward into northern Utah. It ranges from 1 737 to

Figure 18.—*Abies lasiocarpa/Vaccinium globulare* h.t., *Pachistima* phase on a north slope in the Big Hole Mountains west of Driggs, Idaho (2 118 m, 6,950 feet). *Pseudotsuga* and *Picea* dominate an understory of *Abies*. *Vaccinium* dominates a rather diverse undergrowth.

2 652 m (5,700 to 8,700 feet) and represents a geographic variant of the *ABLA/VAGL* h.t. *Pachistima* provides the best nomenclatural distinction because it appears in most stands of this phase and is totally absent in the *VAGL* phase. This phase indicates a relatively moderate environment and often borders the *ABLA/ACGL* h.t. or the *Pseudotsuga* series on warmer sites. Adjacent cool, dry sites are often *ABLA/CARU* h.t. Usually *Pseudotsuga* and *Aster engelmannii* are more prevalent here than in the *VASC* phase (fig. 18).

Vaccinium globulare (*VAGL*) phase.—The *VAGL* phase barely enters our area from Montana. It occurs mainly in the vicinity of Yellowstone National Park where it ranges from 2 255 to 2 438 m (7,400 to 8,000 feet). *Spiraea betulifolia* is a common undergrowth component in this phase.

Soils.—Soil parent materials in the *PAMY* and *VASC* phases were mainly sandstone but also included quartzite, andesite, rhyolite, and granitics. In both phases, the pH was similar; it ranged from 4.6 to 5.8 and averaged 5.3. Areas of bare soil and rock were usually less than 2 percent and average litter depth per site reached 13 cm (5.1 in). Soils data are lacking for the *VAGL* phase.

Productivity/Management.—Timber potential appears low to moderate (appendix E-2). *Pseudotsuga* grows well in the *PAMY* phase and should regenerate easily in small openings. On most sites, *Pinus contorta* readily invades following fire or logging and creates a light canopy that may benefit *Picea* and *Abies* seedlings. When the tree canopy is reduced near the moist extreme of this h.t., *Vaccinium globulare* may increase and compete with conifer seedlings. Most of these sites offer little forage or browse for large herbivores. Berry crops of *Vaccinium*, however, create a periodic demand for these sites by bears, grouse, and humans and may warrant management in some areas.

Other studies.—Both Henderson and others (1976 unpubl.) and Cooper (1975) have described the *ABLA/VAGL* h.t. in our area. It is also reported from Montana (Pfister and others 1977) and central Idaho (Steele and others 1981).

Abies lasiocarpa/Luzula hitchcockii h.t. (*ABLA/LUHI*; subalpine fir/smooth woodrush)

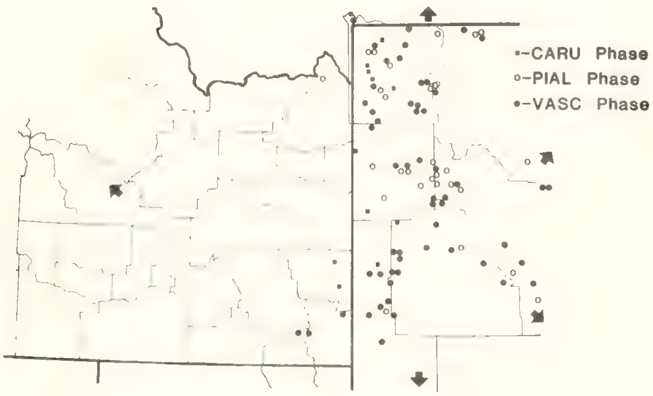
Distribution.—This incidental h.t. occurs locally in the Teton Range. Its main distribution lies in western Montana and central Idaho. *ABLA/LUHI* appears at the upper elevations of the *Abies lasiocarpa* series where snow persists late into the growing season.

Vegetation.—*Picea engelmannii, Pinus contorta*, and *Pinus albicaulis* are considered the common seral dominants, but succession is so slow that *Picea* and *Pinus albicaulis* usually persist in the stand. Patches of *Luzula hitchcockii* usually occur beneath a layer of *Vaccinium scoparium*.

Productivity/Management.—Data from other studies noted below suggest that timber potentials are low and it may be difficult to achieve regeneration after logging. Heavy snowpacks often deform the smaller trees and regeneration of *Abies* may be largely vegetative. The deep snowpacks also indicate that water is a key resource for management consideration.

Other studies.—*ABLA/LUHI* was first described in Montana (Pfister and others 1977) as a slightly broader h.t. It is also described in central Idaho where two phases occur (Steele and others 1981). Only the *Vaccinium scoparium* phase is known from the study area.

Abies lasiocarpa/Vaccinium scoparium h.t. (*ABLA/VASC*; subalpine fir/grouse whortleberry)



Distribution.—This h.t. occupies extensive acreages throughout much of western Wyoming and Yellowstone National Park. It extends southward into northern Utah and Colorado and northward into Montana. It is also common in other areas (see other studies). In our study area it ranges from 1 981 to 2 987 m (6,500 to 9,800 feet) and occupies a variety of slopes and aspects at mid- to upper elevations of the subalpine fir series.

Vegetation.—This is one of the most widespread forest h.t.'s in the study area, yet it retains a high degree of floristic homogeneity. *Pinus contorta* dominates seral stands throughout most of the type and *Picea* and *Pseudotsuga* may be present in various amounts depending on the phases noted below. Although *Abies lasiocarpa* is the indicated climax, stands actually dominated by *Abies* are quite rare. A low cover of *Vaccinium scoparium* usually dominates the undergrowth. Other shrubs, if present, are generally sparse and widely scattered.

Calamagrostis rubescens (*CARU*) phase.—This phase ranges from 1 981 to 2 408 m (6,500 to 7,900 feet) and represents the warm lower segment of the h.t. *Pinus contorta* is the major seral dominant; small amounts of *Pseudotsuga* may be present. *Calamagrostis rubescens* may codominate the undergrowth with *Vaccinium* and *Pachistima*. *Geranium viscosissimum* and *Viola adunca* appear more frequently here than in the other phases.

Pinus albicaulis (*PIAL*) phase.—The *PIAL* phase ranges from 2 438 to 2 987 m (8,000 to 9,800 feet) and represents the cold upper elevations of *ABLA/VASC*. It is most common from the Wind River Mountains northward into Montana. *Pinus albicaulis* codominates most stands, with *Abies, Picea*, and *Pinus contorta*. These stands appear more open than in the other phases and apparently afford *Pinus albicaulis* a persistent role in the forest community. Conceptually, this phase represents a transition between the *ABLA/VASC* and *PIAL/VASC* h.t.'s.

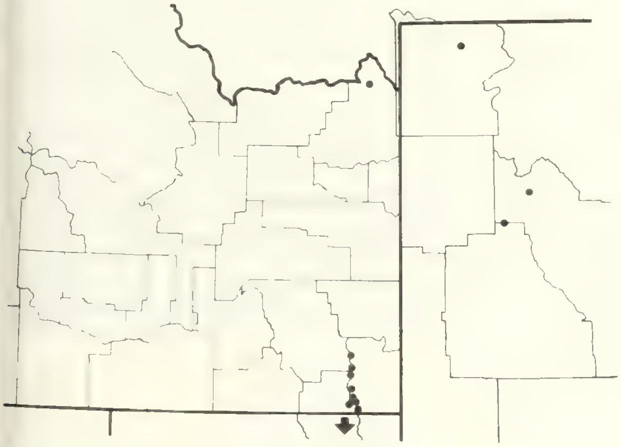
Vaccinium scoparium (*VASC*) phase.—The *VASC* phase ranges from 1 890 to 2 987 m (6,200 to 9,800 feet) and is the most common phase throughout the area. *Pinus contorta* dominates most seral stands until replaced by *Picea* and *Abies*. *Pedicularis racemosa, Pyrola secunda*, and *Arnica cordifolia* are common forbs here but usually have low coverages. As opposed to the other two phases, the *VASC* phase frequently has a conspicuous moss layer. The most common mosses are *Brachythecium collinum, B. velutinum*, and *Polytricadelphus lyallii*.

Soils.—Soil parent materials were mainly sandstone and granitics but also included shale, quartzite, and andesite. The pH ranged from 3.8 to 6.2 and averaged 5.0. Areas of bare rock were usually less than 5 percent but occasionally reached 30 percent. Areas of bare soil were usually less than 1 percent. Average litter depth on a site reached 10 cm (3.9 in). These soil characteristics differed only slightly between phases.

Productivity/Management.—Timber productivity ranges mainly from low to moderate (appendix E-2). *Pinus contorta* will regenerate in unshaded openings but complete overstory removal may be detrimental to existing seedlings of *Picea* and *Abies*. Also, attempts to regenerate trees other than *Pinus contorta* may assume considerable risk. In the *CARU* phase, coverages of *Calamagrostis* may impede tree regeneration unless there is some site preparation. In the *PIAL* phase, timber production is low and regeneration is slow and irregular. Forage production is low on most sites because of short growing season, low numbers of forage species, and shade of the tree canopy. This h.t. often has high watershed value because of heavy annual snowpacks, especially in the *PIAL* phase.

Other studies.—This widespread h.t. has been described in several studies. Cooper (1975) and Henderson and others (1976 unpubl.) have recorded it within the study area and a portion of Reed's (1969, 1976) *Picea engelmannii/Vaccinium scoparium* h.t. also conforms to our description of *ABLA/VASC*. In surrounding areas, *ABLA/VASC* has been reported in the Uinta Mountains of Utah (Pfister 1972a; Henderson and others 1977 unpubl.), the Medicine Bow (Wirsing and Alexander 1975) and Bighorn Mountains of Wyoming (Hoffman and Alexander 1976) and in Montana (Pfister and others 1977). It also occurs in New Mexico and Arizona (Moir and Ludwig 1979), the Front Range of Colorado (Marr 1961; Moir 1969), northwestern Colorado (Hoffman and Alexander 1980), central Idaho (Steele and others 1981), and eastern Washington (Daubenmire and Daubenmire 1968). Similar communities also occur in eastern Oregon (Hall 1973).

Abies lasiocarpa/Arnica latifolia h.t. (*ABLA/ARLA*; subalpine fir/mountain arnica)



Distribution.—The *ABLA/ARLA* h.t. occurs extensively in the Bear River Mountains of southeastern Idaho and adjacent Utah; small areas appear sporadically northward to Yellowstone Park. It ranges from 2 255 to 2 835 m (7,400 to 9,300 feet) and occupies gentle to moderate terrain on all but southerly aspects. It usually appears at mid- to upper elevations of the *Abies lasiocarpa* series and seems to occupy sites where *ABLA/VASC* would occur if *Vaccinium scoparium* were present in the area. Since the *ABLA/VASC* h.t. is absent throughout most of southeastern Idaho and adjacent Utah (Henderson and others 1976 unpubl.), it appears that the *ABLA/ARLA* h.t. is a geographic replacement of *ABLA/VASC* in that area.

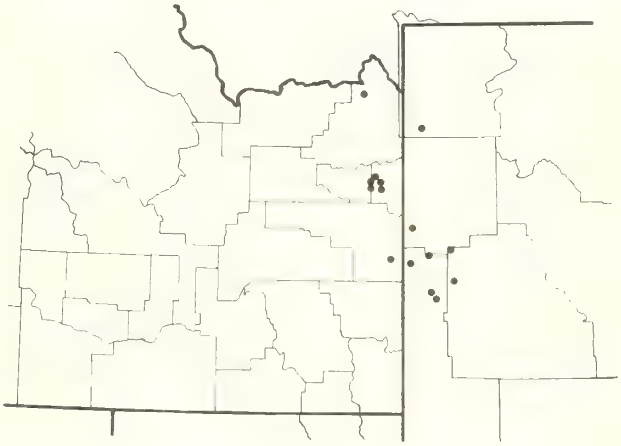
Vegetation.—*Picea engelmannii* is the major seral species throughout the h.t. and usually codominates with *Abies lasiocarpa* in old-growth stands. In portions of this h.t., *Pseudotsuga* and occasionally *Pinus contorta* or *P. albicaulis* may be present. *Ribes montigenum* and *Pachistima* are the most common shrubs and occasionally they dominate the undergrowth. Usually *Arnica latifolia* dominates a forb layer that includes *Aster engelmannii* and *Pedicularis racemosa*. *Arnica latifolia* is often difficult to distinguish from *A. cordifolia* (see taxonomic considerations) and a taxonomic key should be consulted for positive identification.

Soils.—Limited data suggest that soil parent materials included sandstone, quartzite, and andesite. Limited pH data ranged from 5.0 to 5.7 and averaged 5.3. Coverage of bare rock was usually less than 4 percent, but large boulders occurred on some sites and sometimes occupied much of the area. Amounts of bare soil were usually negligible. Average litter depth on a site reached 8 cm (3.1 in).

Productivity/Management.—Timber productivity potential is mostly moderate (appendix E-2). *Picea* grows well on these sites, but successful regeneration may require site preparation and partial shade. *Abies lasiocarpa* seedlings may require the protection of a tree canopy. When present, *Pseudotsuga* or *Pinus contorta* should regenerate easily in unshaded openings. Domestic livestock that feed in adjacent areas may seek shade and shelter on these sites and pose a threat to conifer seedlings. Benefits to big game appear limited to cover.

Other studies.—The *ABLA/ARLA* h.t. was previously described by Henderson and others (1976 unpubl.) in southeastern Idaho and adjacent Utah but has not been reported in any other studies.

Abies lasiocarpa/Symphoricarpos albus h.t. (*ABLA/SYAL*; subalpine fir/common snowberry)



Distribution.—*ABLA/SYAL* is a minor h.t. found mainly in lower drainages of the Greys and Hoback Rivers and in the Snake River Range. It also occurs in the Big Hole Mountains west of Driggs, Idaho, and occasionally northward. This h.t. ranges from 1 737 to 2 316 m (5,700 to 7,600 feet) and occupies benches, lower slopes, and well-drained alluvial terraces. It appears at low elevations of the *Abies lasiocarpa* zone where it often borders the *ABLA/PHMA* h.t. or the *Pseudotsuga* series on warmer sites. Adjacent cool, moist sites are often *ABLA/ACGL* or *ABLA/VAGL*.

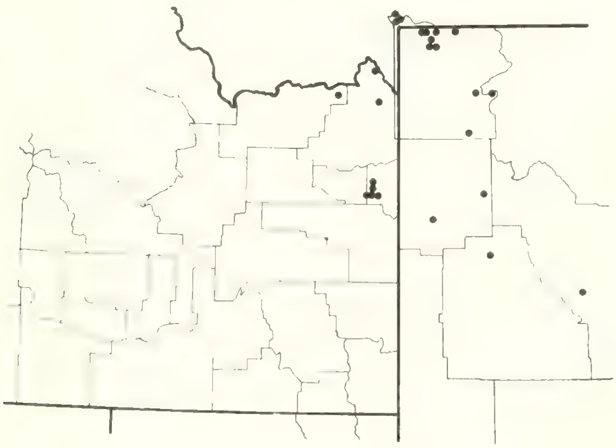
Vegetation.—*Pinus contorta* and *Pseudotsuga* are the major seral conifers; occasionally *Picea engelmannii* is a codominant. Sometimes *Populus tremuloides* is present. *Abies lasiocarpa* may be well represented even in seral stands and codominant with *Pinus contorta* and *Pseudotsuga. Amelanchier alnifolia* often forms a notable layer, especially in seral stands. *Symphoricarpos albus* creates a light canopy throughout the stand and often overtops a layer of *Calamagrostis rubescens*.

Soils.—Soil parent materials were mainly sandstone and occasionally limestone or andesite. The pH ranged from 4.8 to 6.9 and averaged 6.0. Areas of bare rock and bare soil were negligible and average litter depth per site reached 8 cm (3.1 in).

Productivity/Management.—Timber potential ranges from low to high (appendix E-2). Both *Pseudotsuga* and *Pinus contorta* should regenerate easily where the tree canopy has been removed. *Abies* may establish without site treatment but its stocking is apt to be low. Site preparations may be needed when high coverages of graminoids are present. Wintering big game may use these sites extensively because of the gentle terrain and relatively low elevations. Some animals often reduce considerably the palatable browse species. Moose, especially, may retard succession to *Abies lasiocarpa* by destroying the *Abies* regeneration.

Other studies.—This h.t. has not been described in other studies.

Abies lasiocarpa/Thalictrum occidentale h.t. (*ABLA/THOC*; subalpine fir/western meadow-rue)



Distribution.—*ABLA/THOC* is a minor h.t. that occurs mainly from Yellowstone National Park southward into the Wind River Range. It ranges from about 2 316 to 2 713 m (7,600 to 8,900 feet) and occupies gentle to moderately steep terrain on various aspects. It usually represents mid-elevations of the subalpine fir series.

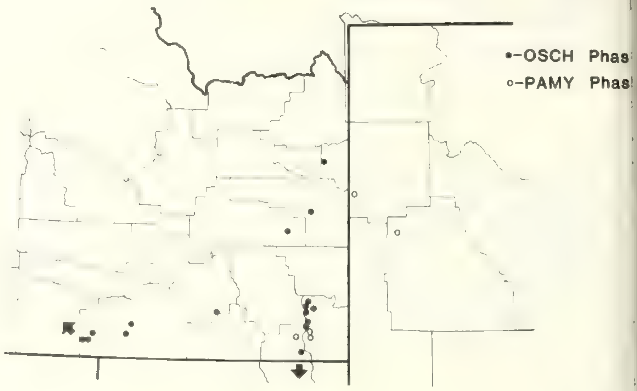
Vegetation.—*Pinus contorta* and *Picea engelmannii* are the most common seral dominants. Occasionally *Pseudotsuga* dominates seral stands and *Pinus albicaulis* may be present in small amounts. Usually *Abies lasiocarpa* regen erates heavily beneath the canopy of seral trees. Althoug several shrub species may be present, forbs generally dominate the undergrowth. Of these forbs, *Thalictrum occidentale, Arnica cordifolia* and *Osmorhiza chilensis* are the most common. *T. occidentale* is difficult to distinguis from a few other species of *Thalictrum* (see taxonomic considerations) and a taxonomic key should be consulted for positive identification.

Soils.—Limited soils data suggest that parent materials may be sandstone, limestone, or quartzite. The pH ranged from 5.1 to 7.0 and averaged 6.1. Areas of bare rock and bare soil were negligible and average litter depth per site reached 5 cm (2 in).

Productivity/Management.—Timber potentials are moderate (appendix E-2). If present, *Pinus contorta* or *Pseudotsuga* should regenerate well in openings. A partial tree canopy may benefit *Picea* and *Abies* seedlings by providing protection from wind and intense sunlight. Big game may seek these sites for the numerous forbs but most of this use would occur during the growing season.

Other studies.—A slightly broader version of this h.t. was described by Cooper (1975) within our study area. No other studies have reported an *ABLA/THOC* h.t.

Abies lasiocarpa/Osmorhiza chilensis h.t. (*ABLA/OSCH*; subalpine fir/mountain sweetroot)



Distribution.—*ABLA/OSCH* is a major h.t. across the southern portion of Idaho and southward into Utah. It ranges from about 1 981 to 2 591 m (6,500 to 8,500 feet) and is most common on northerly to easterly aspects. Usually it represents low to mid-elevations of the *Abies lasiocarpa* series. Adjacent drier sites are often *ABLA/CARU* or nonforest h.t.'s.

Figure 19.—*Abies lasiocarpa/Osmorhiza chilensis* h.t., *Pachistima* phase on an easterly slope in the Eightmile Creek drainage, Bear River Range (2 057 m, 6,750 feet). *Pseudotsuga*, and *Abies* are replacing a stand of *Populus tremuloides* and *Pinus contorta*. *Pachistima* has formed a prominent shrub layer. *Osmorhiza, Arnica, Geranium viscosissimum* and *Calamagrostis rubescens* are the major herbaceous species.

Vegetation.—Although *Populus tremuloides* or *Pinus contorta* may dominate early seral conditions (fig. 19), *Pseudotsuga* is the common seral dominant in most of the h.t. *Abies lasiocarpa* may codominate the site with *Pseudotsuga or Pinus contorta* or form pure stands on sites previously occupied by *Populus tremuloides*. Shrubs other than *Berberis* and *Pachistima* are usually sparse. *Osmorhiza chilensis* or *O. depauperata* are usually a dominant member of a diverse forb layer. Other species characterize the two phases noted below. The two species of *Osmorhiza* are often difficult to distinguish (see taxonomic considerations) but are similar enough in their ecologies to be used as alternate indicators.

Pachistima myrsinites (*PAMY*) phase.—This phase occurs mainly in the Bear River Range and occasionally to the northeast. It ranges from 1 981 to 2 591 m (6,500 to 8,500 feet). *Pachistima* usually dominates the undergrowth; *Osmorhiza depauperata* is a codominant in most forb layers. Other species common to this phase include *Aquilegia coerulea* and *Aster engelmannii*.

Osmorhiza chilensis (*OSCH*) phase.—This phase occurs mainly in the Bear River Range and westward between 2 012 and 2 499 m (6,600 and 8,200 feet). *Osmorhiza chilensis* is often a dominant forb here (fig. 20); frequent associates are *Silene menziesii, Thalictrum fendleri*, and *Viola adunca*.

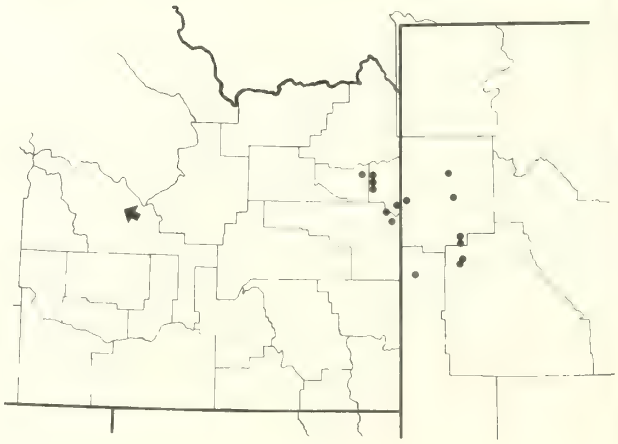
Figure 20.—*Abies lasiocarpa/Osmorhiza chilensis* h.t., *Osmorhiza* phase on a north toeslope in the Eightmile Creek drainage, Bear River Range (2 225 m, 7,300 feet). All-age *Abies* is replacing an overstory of *Pseudotsuga. Osmorhiza* dominates a diverse undergrowth layer.

Soils.—Soil parent materials included shale, limestone, sandstone, quartzite, and dacite. The pH ranged from 5.5 to 7.2 and averaged 6.1. Areas of bare rock or bare soil rarely exceeded 5 percent. Average litter depth on a site seldom exceeded 6.5 cm (2.6 in).

Productivity/Management.—Timber productivity appears moderate to high (appendix E-2). Seral conifers should regenerate easily in small openings. *Abies lasiocarpa* can regenerate beneath the canopy of seral trees and is fairly productive (appendix E-1). Complete removal of the overstory can result in a *Populus tremuloides* community that will persist until replaced by conifers. Shrubs in adjacent nonforest communities, such as *Amelanchier, Prunus, Symphoricarpos*, and *Artemisia*, may also invade large clearcuts. Forage production is limited mainly to forbs that can thrive beneath a light canopy of *Populus tremuloides*.

Other studies.—The *ABLA/OSCH* h.t. has been described from the southern Sawtooth National Forest (Steele and others 1974 unpubl.) and the Caribou National Forest (Henderson and others 1976 unpubl.). It has not been reported in studies of other areas.

Abies lasiocarpa/Spiraea betulifolia h.t. (*ABLA/SPBE;* subalpine fir/white spirea)



Distribution.—*ABLA/SPBE* is a minor h.t. in the Hoback and Greys River drainages and in the Snake River Range. It also is found in central Idaho. It occurs from 2 042 to 2 316 m (6,700 to 7,600 feet) and represents low to mid-

elevations of the *Abies lasiocarpa* series. Usually it occupies westerly to southerly aspects on steep to gentle slopes. *ABLA/SPBE* may border *ABLA/CARU* or *PSME/SPBE* h.t.s on drier sites and *ABLA/VAGL* or *ABLA/ACRU* h.t.s on wetter sites.

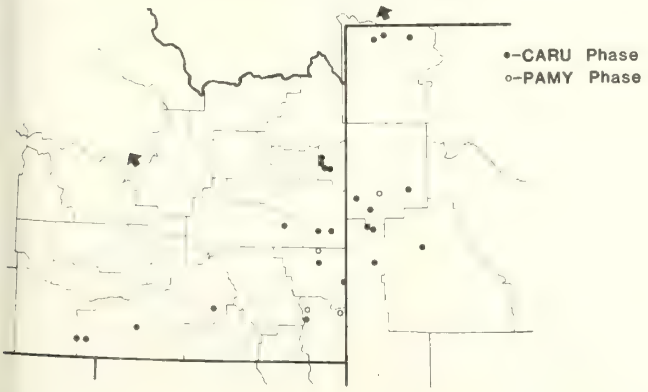
Vegetation.—*Pinus contorta* and *Pseudotsuga* usually dominate seral stands, with *Pseudotsuga* being the more frequent dominant. *Picea engelmannii* may be present in lesser amounts. In most stands, *Abies lasiocarpa* dominates the tree understory. *Amelanchier, Berberis, Sorbus,* and *Lonicera utahensis* are common shrubs here but seldom have high coverages. *Pachistima* is often present and may codominate the shrub layer with *Spiraea*.

Soils.—Soils were derived mainly from sandstone and occasionally limestone or granitics. The pH ranged from 5.3 to 6.4 and averaged 6.0. Usually areas of bare rock and bare soil were nil, but a few sites had boulders that occupy a major portion of the area. Average litter depth on a site reached 4 cm (1.6 in).

Productivity/Management.—Timber productivity potentials are mostly low to moderate (appendix E-2). *Pinus contorta* and *Pseudotsuga* should regenerate easily on seedbeds that receive ample sunlight. If present, *Picea* seedlings may prefer smaller openings that afford some site protection. In most stands, removal of the seral trees without site preparation will hasten succession toward dominance of *Abies lasiocarpa*. Big game seek food and shelter here throughout much of the summer and fall, but domestic livestock are seldom attracted to these sites.

Other studies.—Within the study area this h.t. conforms to portions of Cooper's (1975) *ABLA/VAGL* h.t., *SPBE* phase. *ABLA/SPBE* also occurs in central Idaho (Steele and others 1981) where it lacks *Pachistima* and *Picea*.

Abies lasiocarpa/Calamagrostis rubescens h.t. (*ABLA/CARU;* subalpine fir/pinegrass)



Distribution.—In the study area, *ABLA/CARU* occurs as a major h.t. from about the latitude of Driggs, Idaho, southward. It also occurs in south-central Montana, the adjacent portions of Yellowstone Park and in central Idaho. It is notably absent from much of the Absaroka and Wind River Ranges. This h.t. occupies a variety of aspects on gentle to moderate slopes between 1 859 to 2 591 m (6,100 to 8,500 feet) and represents low to mid-elevations of the *Abies lasiocarpa* series.

Vegetation.—*Pinus contorta* and *Pseudotsuga* are the common seral dominants. *Abies lasiocarpa* usually dominates the understory (fig. 21). *Calamagrostis rubescens,* often accompanied by *Carex geyeri*, creates a conspicuous layer in the undergrowth and shrubs other than *Pachistima* are usually sparse. Forbs such as *Arnica, Geranium*, and *Aster* are generally sparse on undisturbed sites but may be abundant in seral stands.

Pachistima myrsinites (*PAMY*) phase.—This phase appears intermittently throughout southeastern Idaho and adjacent Wyoming where it ranges from 1 981 to 2 499 m (6,500 to 8,200 feet). *Pseudotsuga* is a consistent seral dominant, with *Pinus contorta* appearing less frequently. *Pachistima* usually accompanied by *Berberis repens* forms a layer above the *Calamagrostis*.

Calamagrostis rubescens (*CARU*) phase.—This is the common phase throughout the range of the h.t. In our area, it occurs from 1 737 to 2 377 m (5,700 to 7,800 feet). *Pinus contorta* is the common seral dominant, with *Pseudotsuga* appearing less frequently. Shrubs are generally sparse. *Arnica cordifolia* and *Viola adunca* are the most common forbs.

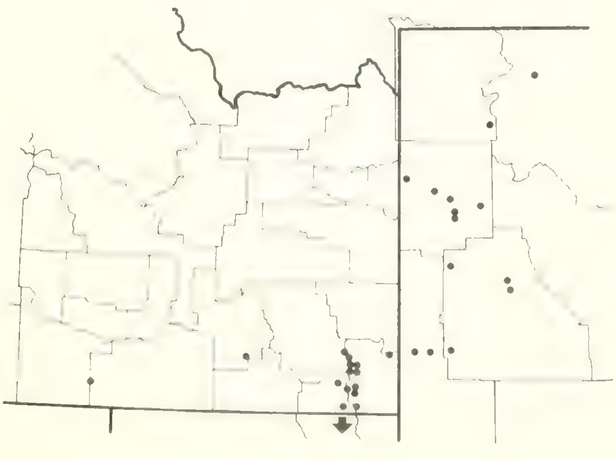
Soils.—Soil parent materials were mainly sandstone. The pH ranged from 4.9 to 6.2 and averaged 5.8. Areas of bare rock or bare soil were usually less than 3 percent. Average litter depth seldom exceeded 7 cm (2.8 in).

Productivity/Management.—Timber productivity potential is low to moderate (appendix E-2). In the *CARU* phase, *Pinus contorta* is the most dependable species for timber production and normally regenerates wherever there is a suitable seedbed with ample sunlight. In the *PAMY* phase, *Pseudotsuga* may be the best suited species for timber management even though regeneration may be difficult to attain. If the overstory is removed, the *Calamagrostis* may increase rapidly and retard seedling establishment. Livestock make light use of this h.t. but are attracted to recent clearings where the forbs and graminoids have acquired renewed vigor. Here the animals may congregate and trample tree seedlings. Big game, especially elk, will feed on the graminoids present. Seral stands may produce some shrubs and forbs with high forage value.

Figure 21.—*Abies lasiocarpa/Calamagrostis rubescens* h.t., *Calamagrostis* phase on a gentle north slope in the McCoy Creek drainage of the Caribou Range (1 905 m, 6,250 feet). *Pinus contorta* dominates an understory of *Abies*. *Calamagrostis* clearly dominates the undergrowth.

Other studies.—The *ABLA/CARU* h.t. was previously described in the study area by Henderson and others (1976 unpubl.). It is also reported from Montana (Pfister and others 1977) and central Idaho (Steele and others 1981).

Abies lasiocarpa/Berberis repens h.t. (*ABLA/BERE*; subalpine fir/Oregon grape)



Distribution.—*ABLA/BERE* is a major h.t. throughout much of Utah and extends northward into southeastern Idaho and western Wyoming. It ranges from 2 012 to 2 713 m (6,600 to 8,900 feet) and usually appears at low to mid-elevations of the *Abies lasiocarpa* series. Usually adjacent warmer sites are in the *Pseudotsuga* series. Although this h.t. occurs on a variety of sites, it is most common on moderate slopes having northerly aspects.

Vegetation.—Usually *Pseudotsuga* dominates seral stands. *Picea* may be present in lesser amounts and occasionally is dominant. In some areas *Populus tremuloides* or *Pinus contorta* will dominate early successional stages. *Abies lasiocarpa* is normally well represented, at least in the smaller size classes. Usually *Pachistima* dominates the undergrowth and is accompanied by *Berberis repens*, but occasionally one or the other is absent. Other common shrubs are *Symphoricarpos oreophilus*, *Shepherdia*, and *Amelanchier*. *Arnica cordifolia* is the most common forb and often has high coverages. The moss, *Brachythecium collinum*, also appeared frequently in this h.t.

Carex geyeri (*CAGE*) phase.—This incidental phase occurs locally from 2 377 to 2 652 m (7,800 to 8,700 feet) in the Bear River Range of southeastern Idaho and becomes more common in northern Utah. *Carex geyeri* which may occur in high coverages is the characteristic feature. This phase appears to be closely related to the *ABLA/CAGE* h.t.

Berberis repens (*BERE*) phase.—This is the common phase found in the study area. Its description generally follows that given for the h.t.

Soils.—Soil parent materials included sandstone, limestone, granitics, quartzite, shale, and basalt. Soil pH ranged from 4.6 to 7.1 and averaged 5.8. Coverage of bare rock was usually less than 5 percent, but in some areas large boulders covered much of the site. Areas of bare soil were generally less than 3 percent. Average litter depth on a site seldom exceeded 7 cm (2.8 in).

Productivity/Management.—Timber productivity ranges from low to high (appendix E-2). *Pinus contorta* or *Pseudotsuga* should regenerate easily on seedbeds that receive ample sunlight. If *Populus tremuloides* is present it can often dominate newly made openings in the stand. *Picea*, if present, and *Abies* should establish easily beneath a light canopy of existing conifers and grow well if free of suppression. Domestic livestock seldom spend much time on these sites but deer may use some areas throughout the summer.

Other studies.—Pfister (1972a) first described the *ABLA/BERE* h.t. in Utah and later Henderson and others (1976 unpubl.; 1977 unpubl.) recognized it in southeastern Idaho. No other studies have reported this h.t.

Abies lasiocarpa/Carex geyeri h.t. (*ABLA/CAGE;* subalpine fir/elk sedge)

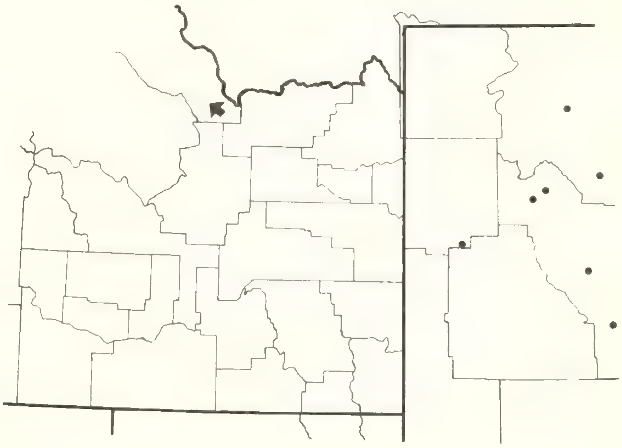
Distribution.—This incidental h.t. occurs in Yellowstone National Park and occasionally southward to the Bear River Range in southeastern Idaho. It appears mainly between 2 377 to 2 896 m (7,800 and 9,500 feet) at mid- to upper elevations of the subalpine fir series.

Vegetation.—*Pinus contorta* is the common seral dominant and small amounts of *Picea* or *Pseudotsuga* are sometimes present. *Pinus albicaulis* appears sporadically throughout the h.t. and becomes increasingly abundant toward the cold extreme. Usually *Carex geyeri* dominates the undergrowth among the sparse layer of forbs. Shrubs are generally scarce.

Productivity/Management.—Data from other studies noted below suggest that timber potentials are low to moderate. *Pinus contorta*, if present, is the only practical species for regeneration. Livestock and big game find little forage here except *Carex geyeri*, which is used by cattle and elk.

Other studies.—*ABLA/CAGE* typically occurs on the coarse granitic soils in central Idaho where a *Carex geyeri* phase and an *Artemisia tridentata* phase are described (Steele and others 1981). Only the *Carex geyeri* phase is known from our area. *ABLA/CAGE* also occurs in Montana (Pfister and others 1977) where an additional *Pseudotsuga menziesii* phase is described; however, most stands in this phase appear to fit our *ABLA/THOC* h.t. *ABLA/CAGE* is also reported from southeastern Wyoming (Wirsing and Alexander 1975). Hoffman and Alexander (1980) report *ABLA/CAGE* in northwestern Colorado, but some of their stands (54 and 29) fit our *ABLA/VASC* and a few others (7, 68, 61) fall within *ABLA/CARU*.

Abies lasiocarpa/Juniperus communis h.t. (*ABLA/JUCO;* subalpine fir/common juniper)



Distribution.—In our area, *ABLA/JUCO* is a minor h.t. along eastern slopes of the Absaroka and Wind River Ranges. It also appears in east-central Idaho. This h.t. occurs mainly on gentle slopes from 2 408 to 2 865 m (7,900 to 9,400 feet) but will also appear in cold air drainages as low as 1 981 m (6,500 feet).

Vegetation.—*Pinus contorta, Picea*, and *Pseudotsuga* are the major seral conifers. Lesser amounts of *Abies lasiocarpa* often codominate with these species in older stands. Large, widely spaced patches of *Juniperus communis* create the dominant aspect in the undergrowth. *Shepherdia* is often present and occasionally has high coverages, especially in younger stands. *Arnica cordifolia* usually dominates the forb layer, which is often quite depauperate.

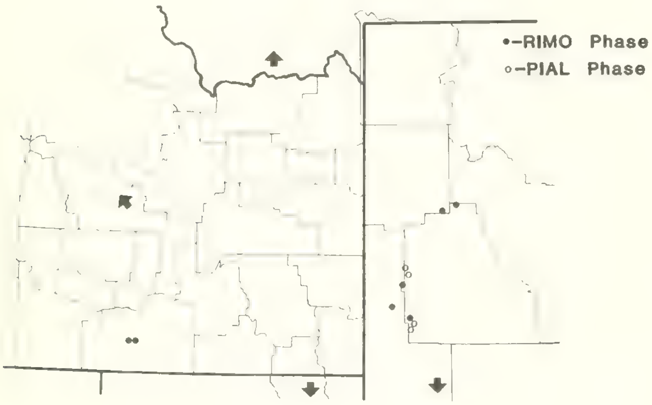
Soils.—The soils were derived mainly from granitics and sandstone and occasionally from shale, andesite, and limestone. The pH ranged from 5.2 to 6.9 and averaged 5.9. Areas of bare rock or bare soil seldom exceeded 5 percent. Average litter depth on a site seldom exceeded 5 cm (2 in).

Productivity/Management.—Timber potentials are low to moderate (appendix E-2). When *Pinus contorta* is present it should establish in clearings that receive full sunlight. Other conifers should establish best under partial shade. Substrate also influences success of the seral tree species. *Pseudotsuga* and *Picea* grow reasonably well on calcareous substrates where *Pinus contorta* does poorly. *Pseudotsuga* is not apt to succeed on sandstone or granitic material.

Livestock find little forage here and seldom use these sites unless grazing areas are nearby. These sites provide cover for deer, elk, and moose that feed in nearby areas. Moose also browse the *Abies* in this h.t.

Other studies.—*ABLA/JUCO* also occurs in central Idaho (Steele and others 1981) where it is more prevalent. A similar condition occurs in Arizona and New Mexico (Moir and Ludwig 1979).

Abies lasiocarpa/Ribes montigenum h.t. (*ABLA/RIMO;* subalpine fir/mountain gooseberry)



Distribution.—*ABLA/RIMO* is a minor h.t. that extends across the study area from Utah to Montana and central Idaho. It appears at upper elevations of the forested zone and seldom occurs below 2 438 m (8,000 feet). It may occupy various slopes and aspects.

Vegetation.—Tree cover varies according to the phases noted below. Undergrowths are often quite depauperate, with *Ribes montigenum* being the only conspicuous shrub. Occasionally the *Ribes* will form a dense layer but more often it occurs in small clumps.

Pinus albicaulis (*PIAL*) phase.—The *PIAL* phase was found along the crest of the Wyoming Range between 2 950 and 3 109 m (9,680 and 10,200 feet). It represents the upper extremes of the *ABLA/RIMO* h.t. and usually merges with alpine communities. Its lower limits border the *ABLA/VASC* h.t., *PIAL* phase, *ABLA/ARLA* or *ABLA/RIMO* h.t., *RIMO* phase. *Pinus albicaulis* is well represented and usually the dominant tree. Stunted *Abies*, and occasionally *Picea*, occur beneath the pine. This phase was recently discovered by Andrew Youngblood (Bridger-Teton National Forest, pers. comm.) who supplied the existing data.

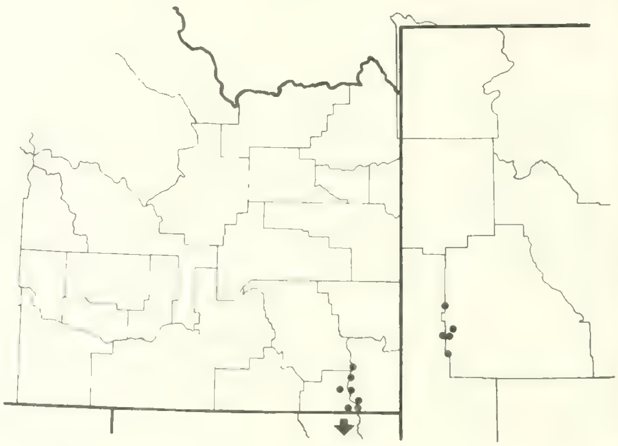
Ribes montigenum (*RIMO*) phase.—This is the more common phase of the *ABLA/RIMO* h.t. and usually occurs between 2 560 and 2 774 m (8,400 and 9,100 feet). *Picea engelmannii* is the major seral species, although *Pinus contorta* is occasionally present (fig. 22). *Pinus albicaulis* may appear in minor amounts. *Abies lasiocarpa* may solely dominate old growth stands or codominate with *Picea*.

Soil.—Soil parent materials were mainly sandstone, and other sedimentaries, but included granitics and quartzite. The pH ranged from 4.0 to 5.4 and averaged 4.8. Areas of bare rock were usually less than 2 percent, but on some sites scattered boulders substantially increased the rock coverage. Areas of bare soil were usually less than 5 percent. Average litter depth per site reached 10 cm (3.9 in).

Productivity/Management.—Timber potential in the *PIAL* phase is nil. In the *RIMO* phase, timber productivity is mostly low to moderate (appendix E-2) and tree regeneration may be sporadic. *Picea* and *Abies* should regenerate best where they receive protection from frost heaving and intense insolation. In southern Utah (Pfister 1972b) it was shown that trees have difficulty getting established in clearcuts because of the severe environment within this h.t. Billings (1969) has described a harsh microclimate on sites resembling *ABLA/RIMO*. Big game and livestock may seek shelter on these sites but find little forage here. Snowpacks persist late into the growing season and provide summer runoff, which may be the most valuable resource.

Other studies.—Pfister (1972a) first described the *ABLA/RIMO* h.t. in Utah. It was later reported from central Idaho (Steele and others 1981), adjacent Montana (Pfister and others 1977), and southeastern Idaho (Henderson and others 1976 unpubl.).

Abies lasiocarpa/Pedicularis racemosa h.t. (*ABLA/PERA;* subalpine fir/pedicularis)



Distribution.—This h.t. occurs mainly in southeastern Idaho and adjacent Wyoming and extends southward into Utah. It ranges from 2 255 to 2 621 m (7,400 to 8,600 feet) and occupies a variety of aspects on gentle to moderately steep terrain. It normally represents mid-elevations of the *Abies lasiocarpa* series.

Vegetation.—*Pinus contorta, Picea*, and sometimes *Pseudotsuga*, are the major seral trees. *Abies lasiocarpa* usually dominates the tree understory. *Symphoricarpos oreophilus* and *Pachistima myrsinites* are common shrubs here, but they usually have low coverages. *Pedicularis*

Figure 22.—*Abies lasiocarpa/Ribes montigenum* h.t., *Ribes* phase on a northeast slope near Commissary Ridge, in the Salt River Range (2 743 m, 9,000 feet). *Picea* and *Abies* dominate an understory of *Abies*. *Ribes montigenum* has formed small patches throughout the stand. The herbaceous layer has numerous species but their coverages are all quite low.

racemosa is common throughout the stand and often dominates the forb layer (fig. 23). Normally, *Arnica cordifolia* is the only other forb with a relatively high coverage and *Aster engelmannii* is usually present.

Soils.—Soils were derived mainly from sandstone and limestone. The pH ranged from 4.6 to 7.1 and averaged 5.6. Areas of bare rock were usually less than 5 percent and bare soil less than 1 percent. Average litter depth on a site reached 8 cm (3.1 in).

Productivity/Management.—Timber potentials range from low to high but are mostly moderate (appendix E-2). *Pinus contorta* grows well here on noncalcareous substrates and should establish easily where competing vegetation is removed. On calcareous substrates, *Picea* and sometimes *Pseudotsuga* should establish in small openings or in partial shade. Overstory removal without site preparation may accelerate succession toward dominance of *Abies*.

Other studies.—The *ABLA/PERA* h.t. was first described by Henderson and others (1976 unpubl.) It has not been mentioned in other studies.

Abies lasiocarpa/Arnica cordifolia h.t. (*ABLA/ARCO;* subalpine fir/heartleaf arnica)

Distribution.—*ABLA/ARCO* is most common in the eastern (continental climate) portion of the study area and occurs in similar areas of east-central Idaho and Montana. In the study area, it is a major h.t. on eastern slopes of the

Figure 23.—*Abies lasiocarpa/Pedicularis racemosa* h.t. on a gentle northwest slope near Middle Piney Lake, Wyoming Range (2 530 m, 8,300 feet). A mixed stand of *Picea, Pseudotsuga*, and *Abies* dominates the site. *Pedicularis racemosa* is the prominent forb of a rather sparse undergrowth.

Wind River, Wyoming, and Absaroka Ranges. It occurs from 2 255 to 2 896 m (7,400 to 9,500 feet) and represents low to mid-elevations of the *Abies lasiocarpa* series. *ABLA/ARCO* can be found on most aspects having gentle to moderate terrain. In a southerly direction along the Wyoming Range the climate becomes progressively drier and *ABLA/ARCO* shifts from south slopes with *ABLA/VASC* on north exposures to north slopes with sage-grass communities on south exposures (Andrew Youngblood, Bridger-Teton National Forest, pers. comm.). Many widespread h.t.'s shift their topographic positions geographically but seldom in such a short distance.

Vegetation.—*Pinus contorta* is usually the dominant seral species but sometimes *Picea* or *Pseudotsuga* is also present. In some areas the *Pseudotsuga* is present only on limestone parent material where *Pinus contorta* is absent. Amounts of *Abies lasiocarpa* vary from codominance with the seral conifers to widely scattered individuals. Shrubs, except *Shepherdia*, are usually sparse. *Arnica cordifolia* generally dominates or codominates a light forb layer.

Astragalus miser (*ASMI*) phase.—This phase occurs mainly from 2 469 to 2 682 m (8,100 to 8,800 feet) on easterly to southerly aspects. *Pinus contorta* is the dominant seral tree and *Picea* is occasionally present in lesser amounts (fig. 24). *Astragalus miser* usually codominates the undergrowth with *Arnica*.

Shepherdia canadensis (*SHCA*) phase.—The *SHCA* phase occurs mainly in the Wind River Range between 2 255 and 2 652 m (7,400 and 8,700 feet). It appears mostly on easterly to northerly aspects on sandstone or granitic parent materials. *Pinus contorta* dominates seral stands and *Pseudotsuga* appears more often here than in the other phases but in lesser amounts. *Shepherdia canadensis* usually dominates the undergrowth even though its coverage gradually decreases toward climax (fig. 25). Succession progresses so slowly on these sites that one can only speculate if *Shepherdia* will persist in the climax stand.

Picea engelmannii (*PIEN*) phase.—This phase appears between 2 316 and 2 896 m (7,600 and 9,500 feet) on moderately steep slopes having northerly aspects. *Pinus contorta* is followed by persistent stands of *Picea* (fig. 26). This is the only phase of *ABLA/ARCO* in our area where *Picea* is a major seral species. As opposed to the other phases, high coverages of moss, mainly *Hypnum rev-*

Figure 24.—*Abies lasiocarpa/Arnica cordifolia* h.t., *Astragalus* phase on a northeast slope near Frontier Creek, southern end of Absaroka Range (2 499 m, 8,200 feet). *Pinus contorta* dominates an undergrowth of *Abies*. *Astragalus* and *Lupinus* are the prominent forbs.

Figure 25.—*Abies lasiocarpa/Arnica cordifolia* h.t., *Shepherdia* phase on a north slope in the Wind River Range northeast of Pinedale, Wyo. (2 518 m, 8,260 feet). *Pinus contorta* dominates the site; *Abies* and *P. albicaulis* are present but sparse. *Shepherdia* is the only undergrowth species having a significant coverage.

Figure 26.—*Abies lasiocarpa/Arnica cordifolia* h.t., *Picea* phase on a steep north slope near Cartridge Creek, southern end of Absaroka Range (2 560 m, 8,400 feet). Large *Picea* dominate an understory of *Abies*. The dead fallen trees are *Pinus contorta. Arnica* dominates a depauperate herbaceous layer. The moss, *Hypnum revolutum* is well represented in the cryptogam layer.

Figure 27.—*Abies lasiocarpa/Arnica cordifolia* h.t., *Arnica* phase on a gentle west slope in the Hams Fork drainage east of Border, Wyo. (2 484 m, 8,150 feet). *Pinus contorta* dominates an understory of young *Abies. Arnica* clearly dominates a depauperate undergrowth.

olutum, are common on these sites. As a result, this phase may resemble the *Picea/Hyre* h.t. in terms of undergrowth as well as topographic position.

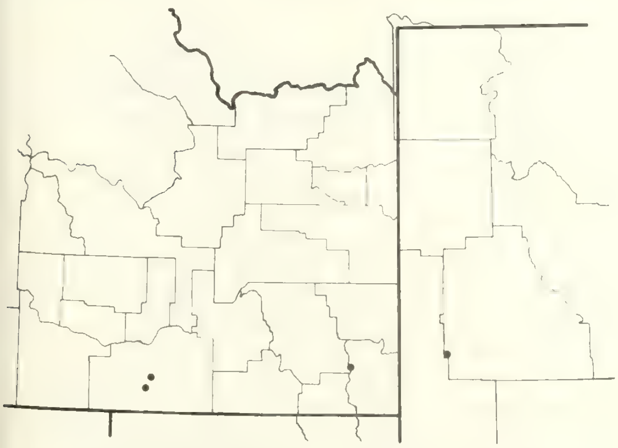
Arnica cordifolia (*ARCO*) phase.—The *ARCO* phase occurs throughout the range of the h.t. from 2 377 to 2 926 m (7,800 to 9,600 feet). It appears on various aspects and follows the general description of the h.t. (fig. 27).

Soils.—Soil parent materials were mainly sandstone, granitics, and quartzite but also include shale, andesite, and occasionally limestone. The pH ranged from 4.1 to 7.1 and averaged 5.5. Areas of bare rock or bare soil were usually less than 2 percent. Average litter depth on a site seldom exceeded 5 cm (2 in). These characteristics differed only slightly between phases.

Productivity/Management.—Timber productivity in most of the type ranges from low to moderate, but some sites in the *ARCO* phase have high potentials (appendix E-2). *Pinus contorta* should establish easily where competing vegetation is removed. It is usually the only suitable timber species except in the *PIEN* phase, where *Picea* should regenerate under a partial tree canopy. In the *SHCA* phase, *Pinus contorta* stands often appear very persistent and may be managed as if the pine were climax; repeated burning may increase the coverage of *Shepherdia*. Domestic livestock and big game find little forage on this h.t., but use the sites for shelter or hiding cover.

Other studies.—The *ABLA/ARCO* h.t. was originally described in Montana (Pfister and others 1977) where it includes a richer herbaceous layer than is described in other studies. *ABLA/ARCO* is also described in central Idaho (Steele and others 1981) and the Bighorn Mountains of Wyoming (Hoffman and Alexander 1976). Cooper's (1975) *Abies lasiocarpa/Thalictrum occidentale* h.t., *Arnica cordifolia* phase relates to our *ABLA/ARCO* h.t.

Abies lasiocarpa/Carex rossii h.t. (*ABLA/CARO*; subalpine fir/Ross sedge)



Distribution.—*ABLA/CARO* is a minor h.t. near the Idaho-Utah border. Small amounts also appear in the Wyoming Range of Wyoming. It occurs from about 2 255 to 2 438 m (7,400 to 8,000 feet) and represents low elevations of the *Abies lasiocarpa* series. It tends to border nonforest communities at the dry extreme and the *ABLA/CARU* or *ABLA/ARCO* h.t.'s at the moist end.

Vegetation.—*Pinus contorta* is the common seral dominant. Small amounts of *Picea engelmannii, Pinus flexilis* and *Populus tremuloides* are occasionally present. In older stands, *Abies lasiocarpa* often codominates with *Pinus contorta. Carex rossii* normally dominates a very depauperate undergrowth. Shrubs are virtually absent.

Soils.—Soil parent materials consisted of quartzite and sandstone. The pH ranged from 5.3 to 6.1 and averaged 5.7. Areas of bare rock and bare soil were less than 2 percent. Average litter depth per site reached only 2 cm (0.8 in).

Productivity/Management.—Timber potentials are probably low and adequate regeneration of *Pinus contorta* may be difficult to attain on these dry sites. The root system of established *Carex rossii* presents severe competition for tree seedlings and site treatment may be needed even though *Carex* interspaces appear adequate for conifer establishment. When *Populus tremuloides* is present it can provide some browse for deer and elk, otherwise forage values are very low for big game and livestock. Animals that feed in adjacent nonforest communities may use these sites for shelter and concealment.

Other studies.—No other studies have described *ABLA/CARO*.

Pinus albicaulis Series

Distribution.—*Pinus albicaulis* h.t.'s are best represented in the rather dry Wind River Range, which is the southeastern limit of the *P. albicaulis* distribution. This series also extends northward and eastward through the Absaroka and Teton Ranges to Montana and Idaho. *Pinus albicaulis* h.t.'s extend downslope from upper timberline on dry, exposed ridges and are best developed on southern to western aspects, though they may occur on any aspect. At its cold extremes this series borders alpine communities usually dominated by *Carex* spp., *Festuca idahoensis*, or *F. ovina*. At lower elevations it merges with dry-cold h.t.'s of the *Abies, Picea*, or *Pinus contorta* series.

These sites are too severe for *Abies* or *Picea*, and even *Pinus albicaulis* is deformed or stunted by wind, cold, and drought on the most exposed sites. On severe sites, *Pinus albicaulis* often develops multistemmed forms which are more prevalent in the Yellowstone-Teton region than in areas to the southeast. On sites less severe, *P. albicaulis* extends downslope as a minor seral species to where it overlaps the highest distributions of *Pseudotsuga*. In some areas, the *P. albicaulis* distribution appears influenced by substrate. This tree occurs strongly on acidic substrates even though it has been recorded on calcareous ones (Weaver and Dale 1974; Forcella 1978; Pfister and others 1977). Its distribution is also strongly influenced by the Clarks nutcracker, which is instrumental in the pine's dispersal and establishment (Lanner 1980). This bird transports large numbers of *P. albicaulis* seed to

caching areas where it deposits 1-5 seeds in the soil at a depth of 2-3 cm (0.8-1.2 in); the preferred caching sites are windswept areas that become free of snow early in the spring (Lanner and Vander Wall 1980; Lanner 1980).

Vegetation.—On exposed upper slopes and ridges, *Pinus albicaulis* is often the sole dominant. On the more gentle slopes protected from severe wind, *P. albicaulis* may codominate with *P. contorta* in older stands. In the relatively younger stands, *P. contorta* is often the dominant tree, with lesser amounts of *P. albicaulis* scattered throughout. For purposes of h.t. classification, these sites should be considered as part of the *P. albicaulis* series because the greater shade tolerance of *P. albicaulis* implies its eventual dominance at climax (Day 1967). Occasionally this long successional trend is accelerated by mountain pine beetles, which kill the *P. contorta* and leave *P. albicaulis* with a greater competitive advantage. An occasional *Pseudotsuga, Picea*, or *Abies* may appear in these stands, but the unfavorable substrates and harsh environments preclude their development and reproduction.

The undergrowths of closed stands are very depauperate but where stands become open, as at upper treeline or the ecotones with other vegetation, richness is increased twofold to fourfold. Undergrowths also increase beneath the more open tree canopies of older stands. *Vaccinium scoparium*, which occurs only on the best sites in this series attains an abundant coverage. Occasionally *Shepherdia* and *Juniperus communis* are well represented in certain h.t.'s. *Arnica cordifolia, Poa nervosa*, and *Carex rossii* are most characteristic of the herbaceous layer but seldom have high coverages.

Insects/Disease.—The mountain pine beetle (*Dendroctonus ponderosae*) has killed considerable *P. albicaulis* in a few localities within the study area: Sawtelle Peak, Union Pass, Togwotee Pass, and the Absaroka Range in Yellowstone National Park. Although these few instances probably do not reflect the actual degree of infestation within the study area, there was little evidence of widespread lethal attacks on *P. albicaulis* in areas where it is climax in spite of obvious attacks (sometimes devastating) on associated *P. contorta*. The white pine blister rust (*Cronartium ribicola*), which threatens survival of *P. albicaulis* in northern Idaho (Daubenmire and Daubenmire 1968), is notably scarce in most of the study area. Local infestations of white pine blister rust have occurred in Yellowstone National Park and in the Raynolds Pass and Sawtelle Peak areas to the west.

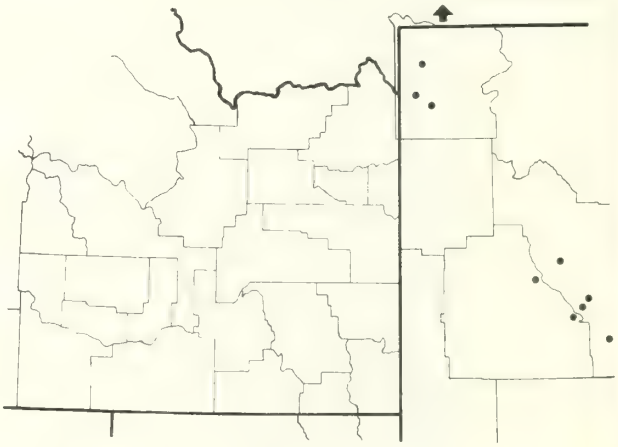
Soils.—This series occurs on soils derived from most major rock types except calcareous sedimentaries, which apparently do not support *P. albicaulis* in this area. Because granitics predominate at upper elevations of the Wind River Range, the soils of most *Pinus albicaulis* h.t.'s are coarse textured and contain relatively high percentages of coarse fraction (particles 2 mm). Other soils characteristics are best treated at the h.t. level.

Fire.—Fire frequency is high owing to the high density of lightning strikes on these exposed upper slopes and ridges. Nevertheless, the inability of fire to spread through the discontinuous canopies and meager undergrowth has enabled numerous stands to attain extreme ages (600 years), high basal areas (appendix E-2), and large biomass (Forcella and Weaver 1977).

Productivity/Management.—The highest elevation h.t.'s in this series produce virtually no commericial timber. In the lower elevation stands, *Pinus contorta* is a persistent seral dominant but is of poor form, with very low site index values. Forage production is poor to fair, even on the most moist sites. Grazing abuse can easily degrade the herb-dominated undergrowths, but where *Vaccinium scoparium* dominates, the sites appear less fragile and have been noted to sustain heavy use by deer and elk that feed in adjacent grasslands. Like the alpine communities, vegetation recovery here is slow and soil erosion can virtually preclude complete restoration. Though highly variable by year, *P. albicaulis* seed crops are sometimes large and provide nutritious forage for birds, rodents, and bears. Often the principal value of these sites is watershed protection and delayed melting of the snowpack. The considerable esthetic appeal of these sites coupled with their low undergrowth and open character has made them popular with recreationists. Unfortunately, these sites are usually fragile and degrade rapidly even when subjected to relatively low levels of recreational use.

Other Studies.—Some habitat types have been recognized and described within this series (Reed 1969; Weaver and Dale 1974; Cooper 1975; Forcella 1978). Other studies (Pfister and others 1977; Steele and others 1981) have noted a diversity of undergrowths within what was termed *Pinus albicaulis* h.t.'s. But they only described these h.t.'s at the series level because of comparably low productivity for all sites and a small data base.

Pinus albicaulis/Vaccinium scoparium h.t. (*PIAL/VASC*; whitebark pine/grouse whortleberry)



Distribution.—*PIAL/VASC* is a major h.t. in the Wind River Range and extends northward to Yellowstone National Park and into Montana. It ranges from about 2 591 to 3 200 m (8,500 to 10,500 feet) and occurs within the highest belt of subalpine forest, usually in concave landforms and other protected positions. Adjacent more severe sites

nay be the *PIAL/CARO* h.t. or grassland. Downslope to nore moist sites, *PIAL/VASC* merges most frequently with he *ABLA/VASC* or *PIEN/VASC* h.t.'s.

/egetation.—*Pinus contorta* is most successful at the low elevations of the h.t. It appears to be long lived on these sites and persists as a dominant or codominant with *P. albicaulis*. Toward upper elevations of the h.t., the prevalence of *P. contorta* diminishes and the replacement by *P. albicaulis* becomes stronger. Occasionally, *Picea* or *Abies lasiocarpa* are present as unthrifty specimens.

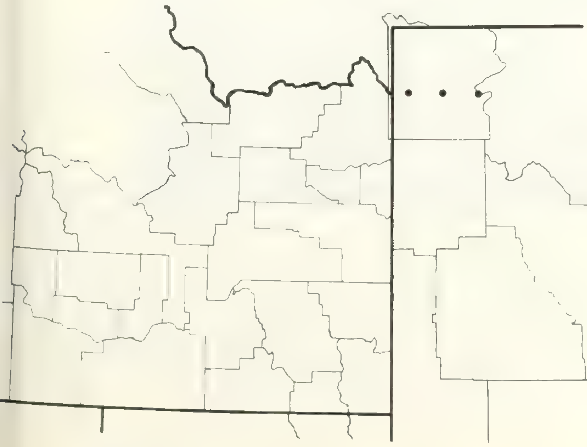
The undergrowth is typified by a layer of *Vaccinium scoparium* that generally does not attain the high coverages found at lower elevations. The shrub and herb layers are notably depauperate; only *Vaccinium scoparium, Poa nervosa, Carex rossii*, and *Arnica cordifolia* exceed 50 percent constancy.

Soils.—Soil parent materials included only granitics and granitic-gneiss mixtures. Other soils data are lacking, but fragmentary evidence suggests pH and percent exposed rock and soil are lower than on adjacent drier sites of the *PIAL* and *PICO* series.

Productivity/Management.—Timber productivity potentials are low to very low (appendix E-2). Some sites provide shelter for deer and elk that feed in nearby grasslands. Recreationists may use these sites for camping but recovery potential from these impacts is low. Watershed values may be relatively high on these sites.

Other Studies.—In Montana the vegetation and site conditions for this habitat type have been described in detail by Weaver and Dale (1974). Its floristics and chorology are documented by Forcella (1978); Forcella and Weaver (1977) have modeled its production and biomass. In the Wind River Mountains, Reed (1969) described a *Pinus albicaulis-P. flexilis/Potentilla diversifolia* h.t., which he later renamed the *P. albicaulis/V. scoparium* h.t. (Reed 1976). Reed's 60 percent constancy for *V. scoparium*, however, indicates that this renamed h.t. does not correspond entirely to our *PIAL/VASC* h.t., which has 100 percent constancy for *V. scoparium*.

Pinus albicaulis/Carex geyeri h.t. (*PIAL/CAGE*; whitebark pine/elk sedge)



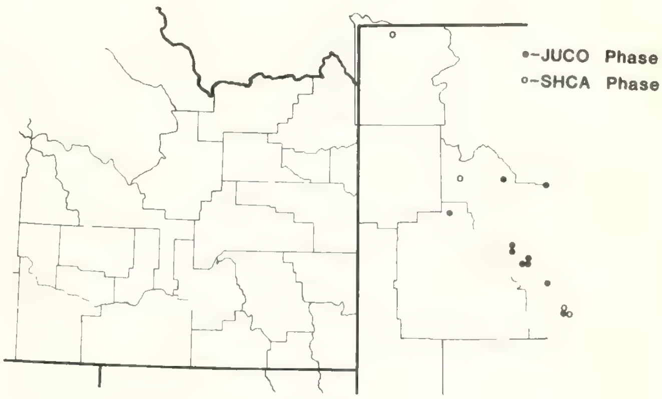
Distribution.—*PIAL/CAGE* is a minor h.t. that was found only in Yellowstone National Park and adjacent Idaho. It ranged from about 2 225 to 2 865 m (7,300 to 9,400 feet) and was usually at the high elevations of the forest zone. It occurs on steep southerly to westerly aspects and at somewhat lower elevations on gentle benches and flats.

Vegetation.—On steep upper slopes, *Pinus albicaulis* is often the sole dominant and is rather widely spaced, with a high proportion of multistemmed forms. On the lower more gentle terrain *P. contorta* is a successful seral dominant, with *P. albicaulis* usually present in lesser amounts. *Carex geyeri* strongly dominates the undergrowth and is usually associated with *Festuca idahoensis, Stipa occidentalis*, and *Trisetum spicatum*. The forb layer is occasionally diverse and belies the relatively dry aspects of these sites.

Productivity/Management.—Our limited data suggest that the greatest values of these sites are snowshed protection, big game cover, and bird and rodent forage.

Other Studies.—Cooper (1975) previously described a somewhat broader *PIAL/CAGE* h.t. in Yellowstone National Park and adjacent Idaho. He also interpreted a *Pinus contorta* phase on the more gentle terrain and a *Pinus albicaulis* phase on the steep upper slopes but the data needed to characterize near-climax conditions of these phases are lacking.

Pinus albicaulis/Juniperus communis h.t. (*PIAL/JUCO*; whitebark pine/common juniper)



Distribution.—*PIAL/JUCO* is a major h.t. in the Wind River Range and appears sporadically in the Owl Creek and Absaroka Ranges and in Yellowstone National Park. It occurs from about 2 438 to 2 987 m (8,000 to 9,800 feet) on droughty sites having gentle slopes. It merges with various community types of the *Pinus contorta* series and with the more moist *PIAL/VASC* and drier *PIAL/CARO* h.t.'s.

Vegetation.—All but the highest elevation sites are strongly dominated by *Pinus contorta*, which may persist as a climax codominant. *P. contorta* reproduces sporadically within the stand and under favorable circumstances may

establish nearly pure stands following fire. The more shade-tolerant *P. albicaulis* establishes very slowly but increases its representation in the stand through prolonged succession. Occasionally, mountain pine beetle accelerates the succession by killing the *P. contorta* and enhancing the competitive advantage of *P. albicaulis*.

Shepherdia canadensis (*SHCA*) phase.—This phase occurs throughout the distribution of the h.t. It ranges from about 2 438 to 2 652 m (8,000 to 8,700 feet) and probably represents the relatively warm low elevations of the h.t. *Pinus contorta* dominates most stands with lesser amounts of *P. albicaulis* scattered throughout. Usually, *Shepherdia canadensis* dominates the undergrowth and *Astragalus miser* or *Arnica cordifolia* are the most prominent forbs.

Juniperus communis (*JUCO*) phase.—The *JUCO* phase occurs mainly in the Wind River Mountains and occasionally in the Owl Creek Mountains. Although it ranges from about 2 438 to 2 987 m (8,000 to 9,800 feet), most sites occur above 2 621 m (8,600 feet), indicating that it probably represents a relatively cold segment of the h.t. *Pinus contorta* dominates most stands while *P. albicaulis* slowly invades the understory (fig. 28). Undergrowths are usually very depauperate, with small amounts of *Juniperus communis, Shepherdia canadensis*, and *Arctostaphylos uva-ursi* as the most common shrubs. *Astragalus miser* is often the most prominent forb, while *Arnica* is usually sparse. During extended periods without fire, *Juniperus communis* appears to achieve higher coverages, but *Shepherdia* shows little ability to increase under any condition.

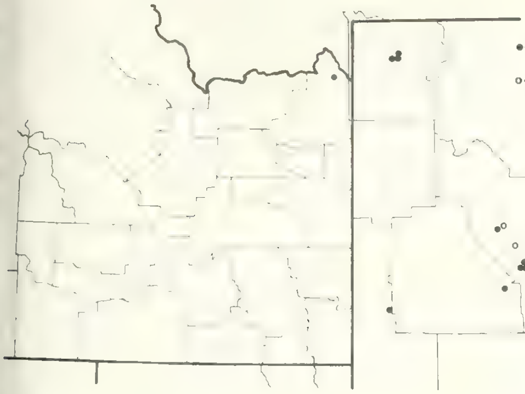
Soils.—Soils in the *JUCO* phase were derived mainly fro granitics and sandstone and occasionally andesite. Limited data suggest that soils in the *SHCA* phase were derived from basalts and sedimentary material. Other soi differences appeared indistinguishable at the phase leve Soil pH ranged from 4.1 to 6.8 and averaged 5.6. Coverag of bare rock ranged from 0 to 38 percent and averaged 5. percent; areas of bare soil ranged from 0 to 15 percent and averaged 1.9 percent. Average litter depths per site, which only reached 5.5 cm (2.2 in), reflect the low productivity of this h.t.

Productivity/Management.—Timber potentials are mostl low and are further reduced by low stockability (appendix E-2). Occasional well-stocked stands may support pole and post cutting. Light use by deer and elk is common, but the forage values are quite low and the animals appear to be using these sites for cover. Livestock seldom use these sites except for occasional shelter.

Other Studies.—Reed's original paper (1969) on Wind River Range habitat types described a *Pinus albicaulis-P. flexilis/Potentilla diversifolia* h.t. and *Pinus contorta* c.t., several stands of which correspond to our *PIAL/JUCO* h.t.

Figure 28.—*Pinus albicaulis/Juniperus communis* h.t., *Juniperus* phase on a gentle west slope in the Middle Popo Agie drainage of the Wind River Range (2 591 m, 8,500 feet). An open stand of *Pinus contorta* dominates the site; *Pinus albicaulis* saplings and small patches of *Juniperus* are scattered throughout the stand. *Lupinus* is the prominent forb.

Pinus albicaulis/Carex rossii h.t. (*PIAL/CARO;* whitebark pine/Ross sedge)



Distribution.—*PIAL/CARO* is a major h.t. in the Wind River Range and Yellowstone National Park. It also appears in the eastern Absaroka, Gros Ventre, and Washakie Ranges and occasionally elsewhere. It occurs from about 2 316 to 3 200 m (7,600 to 10,500 feet) and rarely appears as low as 1 920 m (6,300 feet) on flat terrain. Adjacent drier sites are often *Festuca*-dominated grasslands. At moist extremes this h.t. merges with *PICO/ARCO* or *PICO/JUCO* community types or *PIAL/VASC* or *PIAL/JUCO* h.t.'s.

Vegetation.—Overstory composition varies between phases as noted below. Undergrowths are quite depauperate and have an average combined coverage of only 9 percent (range 2.5 to 35 percent). *Carex rossii* has the highest constancy in the undergrowth and occasionally shows a tendency to dominate.

Pinus contorta (*PICO*) phase.—This is the common phase within the h.t. It ranges from about 2 316 to 2 865 m (7,600 to 9,400 feet) and represents the relatively low warm elevations of the h.t. *P. contorta* dominates most stands, with lesser amounts of *P. albicaulis* scattered throughout (fig. 29). *P. albicaulis* increases with stand age and eventually codominates with *P. contorta*. Occasionally mountain pine beetle kills the *P. contorta*, leaving *P. albicaulis* as the sole dominant. Sometimes small amounts of *P. flexilis* are also present.

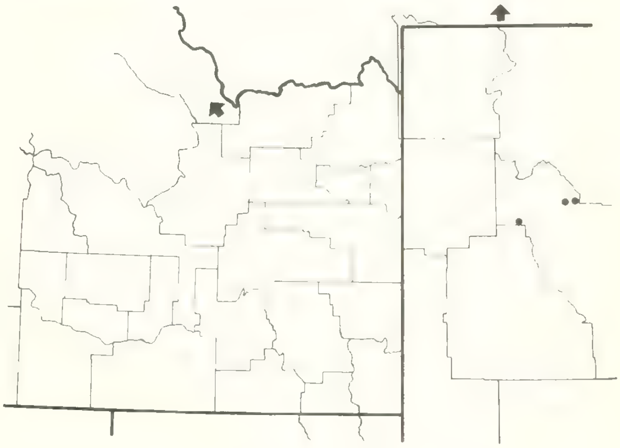
Carex rossii (*CARO*) phase.—The *CARO* phase ranges from about 2 896 to 3 200 m (9,500 to 10,500 feet) and represents the high cold elevations of the h.t. *Pinus contorta* is virtually absent in this phase, leaving *P. albicaulis* to dominate throughout most of the succession.

Soils.—Soil parent materials are predominantly granitics but also include sandstones, basalt, and andesite. The pH ranged from 4.4 to 6.3 and averaged 5.6. The coarse fraction averages a relatively high 19 percent. Coverage of bare soil and rock did not exceed 15 percent and was generally in the range of 1 to 5 percent. Litter depths generally do not exceed 7 cm (2.8 in) and average 3.2 cm (1.3 in).

Productivity/Management.—Timber productivity ranges from very low to moderate but is mostly low (appendix E-2). Forage production is also low. Light use for cover and bedding by deer, elk, and occasionally moose is common in this h.t.

Other Studies.—In the Wind River Range, Reed (1969) described a broad *Pinus albicaulis-Pinus flexilis/Potentilla diversifolia* h.t., which includes our *PIAL/CARO* h.t., *CARO* phase. He later described a *Pinus contorta/Poa nervosa* h.t. (Reed 1976) which apparently includes our *PIAL/CARO* h.t., *PICO* phase. In Yellowstone National Park, Cooper (1975) described a *PIAL/CAGE* h.t., part of which lacks *Carex geyeri* and equates to our *PIAL/CARO* h.t.

Pinus albicaulis/Festuca idahoensis h.t. (*PIAL/FEID;* whitebark pine/Idaho fescue)



Distribution.—*PIAL/FEID* is a minor h.t. that occurs sporadically from the Wind River and Absaroka Ranges to Montana and central Idaho. In the study area it was found from about 2 896 to 2 957 m (9,500 to 9,700 feet) where it represents a dry, cold extreme of the forested zone. Adjacent drier sites are usually nonforested and have *Festuca idahoensis* as the dominant grass. Adjacent more moist sites vary and may be in the *PIAL, ABLA* or *PIEN* series.

Vegetation.—*Pinus albicaulis* is usually the only dominant conifer. An occasional stunted *Picea* or *Populus tremuloides* may be found and a few *Pinus contorta* are sometimes present. A diverse layer of forbs and grasses constitute the undergrowth and often have a high combined coverage. Of these, *Festuca idahoensis* is usually the predominant grass.

Soils.—Limited data suggest that soils were derived from granitics, rhyolite, and mixtures of quartzite and sandstone. The pH ranged from 5.3 to 7.1 and averaged 6.2. Areas of bare soil and rock were less than 1 percent. Average litter depth per site reached 6 cm (2.4 in) but averaged only 2.9 cm (1.1 in).

Productivity/Management.—Timber productivity potentials are very low to low (appendix E-2) and the *Pinus albicaulis* is often of noncommercial quality. Forage production is

Figure 29.—*Pinus albicaulis/Carex rossii* h.t., *Pinus contorta* phase near Louie Lake at the southern tip of the Wind River Range (2 697 m, 8,850 feet). *Pinus contorta* dominates this gentle southwesterly slope. Young *P. albicaulis* are scattered through the stand. *Carex rossii, Poa nervosa*, and *Lupinus argenteus* have the highest frequency in this depauperate undergrowth.

fair and both domestic livestock and big game feed on these sites. This h.t may accumulate only light snowpacks as it often occupies windswept exposures.

Other Studies.—*PIAL/FEID* communities have been mentioned in studies from Montana (Pfister and others 1977) and central Idaho (Steele and others 1981) but were not formally described.

Pinus contorta Series

Distribution.—This series consists of essentially pure stands of *Pinus contorta*, which contain insufficient evidence to indicate that any other tree species is the potential climax. The very broad ecological amplitude of *P. contorta* (Pfister and Daubenmire 1975) permits this series to span the environmental range between the cold portion of the *Pseudotsuga* series and all but the wettest portions of the *Abies lasiocarpa* and *Picea* series. Thus, *P. contorta* community types are common in all but the *Pinus flexilis* series, where they appear only in the *PIFL/JUCO* h.t.

Vegetation.—*Pinus contorta* is a major seral species throughout much of the Rocky Mountains. It is often the first tree to reforest severely disturbed sites and is usually replaced by other conifers within one generation. There appears to be a tendency for *P. contorta* to be only seral on steep slopes and more persistent on gentle terrain. In some broad valleys at upper elevations, *P. contorta* persists for many generations with little or no evidence of replacement. Slopes above such valleys exhibit intermediate situations where *P. contorta* persists but is gradually replaced by *Abies lasiocarpa* and *Pseudotsuga*. On gentle slopes and benches near upper timberline, *Pinus contorta* dominates sites where *P. albicaulis* is apparently the potential climax dominant.

Although *P. contorta* is a pioneer conifer throughout its range, its ability to remain dominant appears related to topoedaphic factors (Pfister and Daubenmire 1975). Upper limits of persistent *P. contorta* stands often resemble a contour and suggest a response to cold air drainage and impoundment. *Pinus contorta* is well adapted to cold air drainages as evidenced by its ability to colonize sites near receding glaciers (Heusser 1969). Over millenia, *P. contorta* seedlings have periodically invaded raw substrates of glacial alluvium and have been subjected to intense daily insolation and nightly cold air accumulation and frost. Today, *P. contorta* still dominates valley floors of glacial

debris in Idaho, Wyoming, and Montana in spite of other coniferous seed sources on adjacent uplands. Although *Abies lasiocarpa* and *Picea engelmannii* extend to upper timberline and replace *Pinus contorta* on steeper slopes, their tolerance of daily temperature extremes on these gentle valleys and droughty soils appears less than that of *P. contorta*.

Undergrowth vegetation obviously varies according to the potential climax of the stand and stocking rate of *Pinus contorta*. Stands that show the greatest potential for being climax to *P. contorta* have the most depauperate undergrowth. Young "dog hair" stands have virtually no undergrowth cover even on relatively moist sites. In this series, unusually low undergrowth coverages, which normally increase as canopy openings increase, provided part of the rationale for the downward adjustment of coverages in the key to h.t.'s when dense stands were encountered.

Soils.—Studies cited below document that *P. contorta* can remain dominant on gentle terrain for many generations and in fact can attain climax status. On these sites *P. contorta* remains dominant by default, owing to the inability of other conifers to colonize these sites. *Pinus contorta* also appears to be favored, and potential competitors reduced in vigor, by particular parent materials, such as sandstones, coarse textured sands, and sandy outwashes derived from rhyolite and granitics. In eastern portions of the study area, *P. contorta* was noted to occur to lower treeline on sandstones but was rarely found on calcareous substrates except on those mixed with other parent materials such as sandstone. Generally, persistent *P. contorta* stands are developed on acidic substrates that exhibit low pH values, mostly less than 6.0.

Fire.—Pure *P. contorta* stands have often been attributed to fire; yet fire is a minor factor in the most persistent stands. Undergrowths in these valley bottom or terrace stands are sparse and produce little fuel. Most of the fuel occurs on adjacent slopes and natural fires on the valley floor that did not ascend the adjacent slopes would be unusual. Yet, quite often only the valley bottom contains nearly pure *P. contorta* and adjacent slopes are in advanced stages of succession to *Abies, Picea,* and *Pseudotsuga.*

As noted above, upper limits of persistent *P. contorta* stands often resemble a contour rather than patterns of previous fires and the cones of *P. contorta* populations are largely nonserotinous. Thus there is little evidence for fire maintaining these stable *P. contorta* stands. In fact, stands which appear closest to a *P. contorta* climax have the widest-spaced trees (without fire scars), the least undergrowth, and gentlest slopes, all of which are unfavorable to fire spread. There are other valley and bench areas that have experienced repeated burnings, but these sites frequently show evidence of repeated fires and produce enough fuel to generate an effective burn.

Productivity/Management.—Timber potentials should range from very low to moderate, depending on the h.t. involved. From a practical standpoint, most of these stands can be managed as if *Pinus contorta* were climax even though other conifers may eventually invade the stand.

Deer, elk, and moose use these stands for cover, but seldom find much forage. These stands usually lack the structural diversity sought by lesser wildlife but may have some value to wildlife or livestock, depending on existing undergrowth and types of cover.

Most of these sites have gentle terrain, which provides easy access and development for recreation facilities. Recreationists, however, may prefer areas that receive less frost and have a less monotonous appearance. Recreational impacts may be low on these gentle slopes, but recovery rates are apt to be slow.

The community types (c.t.'s) of this series represent situations in which *P. contorta* may be the only conifer on the site. On some sites this situation occurs only in initial stages of secondary succession and indications of the potential climax community are usually evident. On other sites, climax indicators invade more slowly and *P. contorta* is a more persistent dominant. Here, determining the habitat type is more tenuous and often requires thorough investigation of the immediate and adjacent sites. There are a large number of h.t.'s among the *Abies, Picea, Pseudotsuga*, and *Pinus albicaulis* series that can support pure *Pinus contorta* stands when other seed sources are absent (appendix B). If the undergrowth indicator species are present, these stands can usually be assigned to the proper h.t. by using the key to *P. contorta* c.t.'s. Other sites where the climax status for *P. contorta* is in question can be treated as c.t.'s. From a practical point, these c.t.'s can be managed as if *P. contorta* were climax even though *Pseudotsuga, Picea, Abies*, or *Pinus albicaulis* may eventually invade the stand. Although several conditions on gentle terrain appear to support *P. contorta* climax, no recognizable situation in the study area was found that consistently maintains *P. contorta* as the sole climax dominant. It is possible, however, that *P. contorta* h.t.'s do exist but have undergrowths similar to those of the other tree series.

Other Studies.—*Pinus contorta* also exists as a persistent dominant in other regions. In south-central Oregon, Franklin and Dyrness (1973) describe climax stands of *P. contorta* on pumice soils. These stands occur on micro-reliefs that impound cold air to the exclusion of *P. ponderosa* occurring upslope. Pfister and others (1977) and Cooper (1975) describe a *P. contorta/Purshia tridentata* h.t. near West Yellowstone, Mont. The plant community here occurs on extensive obsidian-rhyolite outwash sands of the Madison River Valley and is remarkably similar to that of the south-central Oregon pumice deposits. Occupying the vast rhyolitic Central Plateau of Yellowstone Park is a *P. albicaulis/Carex geyeri* h.t., *P. contorta* phase (Cooper 1975), that contains a number of stands which presently support a *P. contorta/Carex rossii* c.t. In central Idaho, Steele and others (1981) have described a *P. contorta/Festuca idahoensis* h.t. that occurs on broad alluvial deposits. For the Bighorn Mountains of Wyoming, Hoffman and Alexander (1976) characterize *P. contorta/*

Arctostaphylos uva-ursi and *P. contorta/Vaccinium scoparium* h.t.'s and Despain (1973) has shown areas of *P. contorta* dominance to be associated with granitic and sandstone substrates. In the Wind River Mountains, Reed (1976) recognized a fairly broad *P. contorta/Poa nervosa* h.t. which apparently includes our *PIAL/JUCO* and *PIAL/CARO* h.t.'s and several *P. contorta* c.t.'s. On the Colorado Front Range, Moir (1969) described a stable zone of *P. contorta* that relates to gentle, undulating terrain rather than adjacent canyon topography. In northwestern Colorado, Hoffman and Alexander (1980) report a *P. contorta/Shepherdia canadensis* h.t.

Pinus contorta/Linnaea borealis c.t. (*PICO/LIBO;* lodgepole pine/twinflower)

Distribution.—*PICO/LIBO* is most apt to occur from the Wind River Mountains northward to Yellowstone National Park. It occupies mostly benches and lower slopes having northerly to easterly aspects. It appears mainly at low to mid-elevations of the *Abies lasiocarpa* zone and at mid-elevations of the *Picea* zone.

Vegetation.—Either *Vaccinium scoparium* or *Berberis, Shepherdia, Rosa*, and *Vaccinium globulare* are prominent shrubs, depending on the h.t. and phase involved. *Linnaea borealis* is common throughout the stand even though other shrubs may dominate the undergrowth. Usually, *Arnica cordifolia* is the most common forb.

Productivity/Management.—*Pseudotsuga, Picea* or *Abies* should invade these sites fairly rapidly. This c.t. represents early successional stages on the *PIEN/LIBO* and *ABLA/LIBO* h.t.s. Management guidelines for *PICO/LIBO* should be comparable to these two h.t.'s.

Pinus contorta/Vaccinium globulare c.t. (*PICO/VAGL;* lodgepole pine/blue huckleberry)

Distribution.—The *PICO/VAGL* c.t. is likely to occur from Yellowstone Park south to Utah, but is absent in the Wind River Range, the southern end of the Absaroka Range, and east slope of the Wyoming Range. Extensive stands occur in the Island Park Basin. It may be found on moist slopes or, more likely, benches having northerly to easterly aspects.

Vegetation.—Usually *Vaccinium globulare* dominates the undergrowth and is accompanied by *Lonicera utahensis*. *Calamagrostis rubescens* and *V. scoparium* may be well represented.

Productivity/Management.—Because these sites favor reproduction of *Pseudotsuga, Picea*, and *Abies*, this c.t. is relatively rare. Only the earliest stages of secondary succession following widespread wildfire represent this c.t. Most of this c.t. occurs on the *ABLA/VAGL* h.t., but on the Targhee National Forest it may also occur on *PSME/VAGL*. *Pinus contorta* productivity on these sites is likely to be comparable to that of *Picea* and *Pseudotsuga*.

Pinus contorta/Vaccinium scoparium c.t. (*PICO/VASC;* lodgepole pine/grouse whortleberry)

Distribution.—In the study area, the *PICO/VASC* c.t. appears mostly in western Wyoming and is widespread in the Wind River Mountains. It can be found on a variety of slopes and aspects at mid- to upper elevations of the *Abies lasiocarpa* zone and lower *P. albicaulis* zone.

Vegetation.—A low cover of *Vaccinium scoparium* usually dominates the undergrowth. Other shrubs, if present, are usually sparse and well scattered. A few forbs such as *Arnica cordifolia* and *Lupinus* spp. are often present and may attain high coverages in patches. *Pinus albicaulis* may be present, but weakly represented.

Productivity/Management.—Most *PICO/VASC* c.t.'s in the study area occupy the *ABLA/VASC* or *PIEN/VASC* h.t., but on gentle slopes and broad benches an occasional *PICO/VASC* c.t. may appear so persistent as to suggest a *P. contorta* climax. Many of these latter situations are probably a *PIAL/VASC* h.t. Farther east in the Bighorn Mountains where *Pinus albicaulis* is rare, Hoffman and Alexander (1976) have described a *PICO/VASC* h.t. that is virtually identical to the *PICO/VASC* c.t. *Pinus contorta* is the most suitable timber species, but productivities will vary depending on the h.t. involved. Although these stands seldom produce much forage for livestock or big game, deer, elk, and moose frequently use them for cover.

Pinus contorta/Spiraea betulifolia c.t. (*PICO/SPBE;* lodgepole pine/white spirea)

Distribution.—The *PICO/SPBE* c.t. may occur from Palisades Reservoir northward to Yellowstone Park. It may be found on various aspects of gentle slopes and benches near the contact of the *Pseudotsuga* and *Abies* zones.

Vegetation.—*Spiraea betulifolia* usually dominates the undergrowth, but it may be subordinate to *Calamagrostis rubescens*, especially in early successional stages.

Productivity/Management.—This c.t. is apparently scarce and represents early stages of secondary succession on the *ABLA/SPBE* or *PSME/SPBE* h.t.'s. Inspection of surrounding sites should indicate the climax potential. The appropriate h.t. description may be consulted for management implications.

Pinus contorta/Calamagrostis rubescens c.t. (*PICO/CARU;* lodgepole pine/pinegrass)

Distribution.—The *PICO/CARU* c.t. occurs most often in the vicinity of Yellowstone Park and the Island Park Basin but may occur southward to the Idaho-Utah border. It occupies various cool, dry aspects having gentle to moderate relief.

Vegetation.—*Calamagrostis rubescens* and *Carex geyeri* often dominate the undergrowth. Shrubs are sparse but may include *Prunus, Berberis, Pachistima, Amelanchier*, and *Symphoricarpos oreophilus*.

Productivity/Management.—Depending on location, the *PICO/CARU* c.t. varies from a clearly seral to a persistent successional stage. It usually occupies either the *ABLA/CARU* or *PSME/CARU* h.t. The more persistent *PICO/CARU* c.t.'s are most likely to occur on the

BLA/CARU h.t. If *Prunus, Berberis,* or *Symphoricarpos reophilus* are well represented, the site is most apt to be *PSME/CARU* h.t. Inspection of less disturbed sites neary may indicate which h.t. is appropriate. If the site indiates more affinities with *ABLA/CARU*, then *P. contorta* hould be the most manageable tree for timber. If the site hows stronger affinities with *PSME/CARU*, then either *P. ontorta* or *Pseudotsuga* may be desirable timber species. the h.t. cannot be determined, management guidelines or *ABLA/CARU* would best apply.

inus contorta/Carex geyeri c.t. (*PICO/CAGE;* lodgepole pine/elk sedge)

istribution.—The *PICO/CAGE* c.t. is most common on he granitic substrates of central Idaho but also occurs in 'ellowstone National Park where it appears most requently on the vast rhyolitic flows. It usually occupies he cool, dry aspects of relatively gentle terrain.

/egetation.—Normally *Carex geyeri* dominates a depauerate undergrowth that contains only a few forbs. *Arnica ordifolia* and *Lupinus* spp. are the forbs having the ighest coverage and constancy. Shrubs are seldom onspicuous.

roductivity/Management.—Most *PICO/CAGE* c.t.'s ocupy the *ABLA/CAGE* h.t., especially on acidic volcanics, r the gentle terrain of the *PIAL/CAGE* h.t. In either case, *P. contorta* is the most suitable timber species but roductivities may vary between h.t. Unless inspection of djacent areas clearly indicates a position within the *Abies lasiocarpa* zone, management guidelines for the *PIAL/CAGE* h.t. would best apply.

Pinus contorta/Juniperus communis c.t. (*PICO/JUCO;* lodgepole pine/common juniper)

Distribution.—This c.t. may appear in moderate amounts, particularly near the eastern periphery of the study area. It has been noted in the southeastern portions of the Absaroka Range, the Owl Creek Mountains, and at upper elevations on granitics and sandstones in the Wind River Range. Though recorded on various aspects of steep topography, it was noted to be most extensive on gentle benches.

Vegetation.—Usually *Juniperus communis* is well represented but recent burns may have reduced its coverage. *Shepherdia canadensis* is usually present and may dominate the undergrowth, particularly on sandstones. *Arnica cordifolia, Lupinus* spp., and *Carex rossii* are usually present but have low coverages in a depauperate herb layer.

Productivity/Management.—The *PICO/JUCO* c.t. may occupy *PSME/JUCO, PIEN/JUCO, ABLA/JUCO,* and *PIAL/JUCO* h.t.'s as a seral community. If one remains on the same parent material, inspection of adjacent sites with a longer post-disturbance recovery time should indicate to which climax series and h.t. a *PICO/JUCO* c.t. site belongs. *Pinus contorta* should be the easiest tree to regenerate but on some sites *Pseudotsuga* may be more productive. In most cases management guidelines should conform to those for the closest determinable h.t. that has an undergrowth dominated by *J. communis*.

Pinus contorta/Shepherdia canadensis c.t. (*PICO/SHCA;* lodgepole pine/russett buffalo-berry)

Distribution.—The *PICO/SHCA* c.t. is apt to appear throughout much of the study area but is most common in the Wind River Range and southern end of the Absaroka Range. It can range from the cool extremes of the *Pseudotsuga* zone to the warm extremes of the *Pinus albicaulis* zone. It may occupy a variety of slopes and aspects but is most common on gentle toeslopes and benches.

Vegetation.—*Shepherdia canadensis* usually dominates the undergrowth, which in some cases is very depauperate. *Arnica cordifolia* usually dominates a sparse forb layer. Graminoids usually are scarce.

Productivity/Management.—The *PICO/SHCA* c.t. could occur on a wide range of h.t.'s, but it is generally an early to mid-seral stage of the *PSME/JUCO, PIEN/JUCO, ABLA/JUCO, ABLA/ARCO* or *PIAL/JUCO* h.t.'s. Inspection of adjacent stands should help to narrow the h.t. determinations to one or two possibilities. In most situations, *Pinus contorta* is the best suited species for timber management but productivity may.vary considerably between h.t.'s.

Pinus contorta/Arnica cordifolia c.t. (*PICO/ARCO;* lodgepole pine/heartleaf arnica)

Distribution.—The *PICO/ARCO* c.t. may be found in the southern Absaroka Mountains and Owl Creek Range southwestward to the Bear River Range. It also occurs in east-central Idaho. This c.t. occupies various aspects on gentle terrain at mid- to upper elevations of the forested zone.

Vegetation.—Pure stands of *P. contorta* are most common, but occasionally small amounts of *P. albicaulis* or *P. flexilis* are also present. *Arnica cordifolia* usually dominates a depauperate undergrowth but occasionally *Pyrola secunda* has higher coverage. *Antennaria racemosa* and *Astragalus miser* may also codominate. *PICO/ARCO* c.t.'s become increasingly stable in age structure southeastward through the Wind River Range and some resemble h.t.'s near their southeastern limits.

Productivity/Management.—*PICO/ARCO* c.t.'s occupy the *ABLA/ARCO, ABLA/JUCO, PIEN/ARCO, PIEN/JUCO, PIAL/JUCO*, and to a lesser degree the *PSME/ARCO* and *PSME/JUCO* h.t.'s. *Pinus contorta* should regenerate better than other conifers on these unproductive sites. On some sites, productivities of *Pseudotsuga* and *Picea* may be comparable to that of *P. contorta*. In most areas, attempts to regenerate *Pseudotsuga* on granitic or sandstone parent materials will have a low probability of success.

Pinus contorta/Carex rossii c.t. (*PICO/CARO;* lodgepole pine/Ross sedge)

Distribution.—The *PICO/CARO* c.t. was found mainly in Yellowstone National Park and vicinity on the extensive rhyolite and tuff formations, and in the Wind River Range (fig. 30). It generally occupies gentle terrain at mid-elevations of the *Abies lasiocarpa* zone, but in the Wind

Figure 30.—A *Pinus contorta/Carex rossii* community type on a gentle bench near the southern end of the Wind River Range (2 621 m, 8,600 feet). *Pinus contorta* dominates the site and the dead fallen trees are also *P. contorta*. *Carex rossii* has the highest frequency in this depauperate undergrowth. This site is most likely a *PIAL/CARO* h.t., *PICO* phase or possibly an undescribed *PICO/CARO* h.t.

River Range was also noted in the *Pinus albicaulis* zone on steep topography and granitic soils.

Vegetation.—Open stands of pure *Pinus contorta* dominate the site and small amounts of *Picea, Abies lasiocarpa*, and *Pinus albicaulis* may occur. Undergrowths are very depauperate; *Lupinus argenteus, Solidago multiradiata, Sedum lanceolatum, Pyrola secunda*, and *P. virens* (*P. chlorantha*) are the herbs of highest constancy; *Poa nervosa* and *Carex rossii* are the most common graminoids. Of these, *Carex rossii* shows the greatest tendency to dominate.

Productivity/Management.—This c.t. is usually found on the *PIAL/CARO* h.t., *PICO* phase, but may also occur on *ABLA/CARO* and more severely disturbed *ABLA/ARCO, ABLA/PERA* and *PIEN/ARCO* h.t.'s. It was also observed as an early seral stage on clearcut, burned, and grazed *ABLA/VASC*.

Populus tremuloides Series

Populus tremuloides dominates a variety of sites within the study area. It is relatively scarce in the northern periphery of the study area, but it becomes increasingly prevalent to the south and east. Its successional role varies from a purely seral species to persistently seral and even climax. The most apparent climax stands are those that occur beyond the lower limits of conifers. These stands frequently occupy concave slopes of low hills and even occur in the *Artemisia tridentata* zone on basalt talus, lava tubes, and boulder fields.

In terms of succession, the stands bordering coniferous forest are the most perplexing. The *Populus* here are often vigorous and will quickly invade adjacent sites when the conifers are removed. These stands often contain an occasional healthy conifer that shows little sign of increasing in the stand. In seemingly pure *Populus* stands a diligent search sometimes reveals a few conifer seedlings that are healthy but damaged by rodents and grazing animals. On these sites it is questionable that conifers will ever replace *Populus*. These plant communities have been classified in much of the study area by Youngblood (1979).

Within the zone of coniferous forest, *Populus* stands tend to become more clearly seral. Here *Populus* occupies sites where fire or logging has removed the conifers or

where landslides have provided a fresh substrate. Conifers may reclaim these sites fairly rapidly but in some areas conifer establishment appears retarded by a lush development of seral forbs and graminoids. In these cases conifer establishment sometimes is confined to the raised microsites of fallen *Populus* logs.

Undergrowths of *Populus* stands vary considerably, but generally resemble the undergrowths of adjacent conifer-dominated communities; most often these coniferous communities are in the *Pseudotsuga* series or warm portion of the Abies series. Where *Populus* is obviously climax, the undergrowth often relates to the adjacent *Symphoricarpos oreophilus/Artemisia tridentata* communities and may form a *P. tremuloides/S. oreophilus* association as broadly described by Reed (1971) and refined by Youngblood (1979).

Populus communities are heavily utilized by domestic stock, often to the point of becoming significantly modified in composition. *Nemophila breviflora, Dactylis glomerata, Cerastium arvense, Rudbeckia occidentale*, and *Poa* and *Helianthella* spp. are typical of abused stands. A number of exclosures in the Yellowstone National Park area indicate that wintering big game populations are capable of significantly modifying *Populus* communities. Severe browsing by elk and moose on *Populus* root sprouts may gradually convert the older decadent stands to shrub- or forb-dominated sites (Krebill 1972).

Other Forest Vegetational Types

Though this classification attempts to treat most forest land in the study area, several situations that support trees were intentionally excluded.

Juniperus osteosperma Communities

In southern portions of the study area, *Juniperus osteosperma* forms extensive stands on the foothills below the coniferous forest zone. A yet more depauperate community of *J. osteosperma*, with minor amounts of *Pinus flexilis*, occurs on scablands and rock outcrops below the forest border in basins to the east of the Wind River, Owl Creek, and Absaroka Ranges.

Juniperus scopulorum Communities

In the Snake River Range and immediately south of Island Park, *Juniperus scopulorum* occasionally appears in pure stands or mixed with *Cercocarpus ledifolius*. These stands occur below the limits of *Pseudotsuga* or occupy lithosols of south to southwest aspects. Similar conditions without *C. ledifolius* are reported in Montana (Pfister and others 1977) but were not sampled. No effort has been made to classify these communities in the Pacific Northwest.

Acer grandidentatum Communities

In parts of southeastern Idaho and adjacent Wyoming, communities dominated by *Acer grandidentatum* are interposed between the *Pseudotsuga* series and *Populus tremuloides* or sage-grass communities. Some undergrowths in these *Acer* stands are comparable to those of *Pseudotsuga* h.t.'s; others are not. *Acer grandidentatum* communities are part of an extensive mountain shrub zone that is more common in Utah and Nevada where classification of these sites should be initiated.

Flood Plain Communities

A few of the larger rivers, such as the Snake (both forks), Wind, Green, and Shoshone, form flood plains or at least a broad braided course where they encounter more gentle terrain. Various combinations of *Picea pungens, P. engelmannii, Populus trichocarpa, P. angustifolia, P. balsamifera, Betula occidentalis, Crataegus douglasii, Elaeagnus commutata, Salix* spp. and certain other trees and shrubs combine to form a series of bottomland communities. The conifers are usually weakly represented, but *P. pungens* and *P. engelmannii* appear to constitute climax species on long-stabilized alluvium in certain locations. In Jackson's Hole, Forsgren (1977 unpubl.) and Reed (1952) report for two limited stretches of the Snake River the possibility of succession from *Salix*- and *Populus*-dominated communities to *Picea*-dominated stands, though the great majority of *Populus*-dominated stands will remain as such. Fluctuations in stream activity continually alter water tables and courses and cyclic floods modify soil depths and substrate composition. For these reasons many riparian situations have unstable vegetation potential and do not lend themselves to the "potential-climax" habitat type concept.

INDIVIDUAL ATTRIBUTES OF HABITAT TYPES

Soils

Characteristics of the upper 10 cm (3.9 in) of soil are summarized in appendix D–1 and as a paragraph in most habitat type descriptions. Rock samples were examined in the laboratory by soil scientists (James Clayton, Intermountain Forest and Range Experiment Station, and Jeff Lelek, University of Montana) to determine the parent material. Air-dry samples were weighed, sieved (2 mm) to separate the gravel, and reweighed to determine percent gravel content. The soil separate was tested for pH with a glass electrode pH meter in a water paste solution.

Soil sampling and analyses were designed to obtain a simple characterization of surface soils for each habitat type, rather than detailed soil-vegetation relationships. Even our limited data (appendix D–1) make it evident that some habitat types are strongly influenced by edaphic or topo-edaphic factors and have a narrow range of soil characteristics. Certain *Pinus flexilis, Pseudotsuga*, and *Picea* h.t.'s show a strong affinity for calcareous substrates. Several habitat types such as *PIEN/CALE, PIEN/CADI*, and *ABLA/CACA* occur where water tables are close to the surface at least part of the year. Other habitat types such as *PSME/ARCO, ABLA/ARCO*, and *ABLA/VASC* occur on a broad range of soils. Some of the wet-site habitat types commonly have the greatest litter accumulations and the least exposed soil and rock. In contrast, some of the most severe habitat types have the least litter and greatest areas of exposed soil and rock.

It is often theorized that vegetation or habitat types can be predicted from soil characteristics. But R. and J. Daubenmire (1968) have emphasized that an overall correlation between habitat types and soil types (classified on the basis of standard soil profile characteristics) is too weak to allow prediction of habitat types from soil types, or vice versa, even though correlations often exist locally. We support this viewpoint as a general rule for several reasons. First, the development of a soil profile reflects a long-term integration of soil forming factors, whereas vegetational development is much more sensitive to current climatic conditions. Second, soil classification systems are not designed to primarily reflect influences on vegetational development; therefore, predictive capabilities should not necessarily be expected. Third, vegetational development depends on many factors, of which soil characteristics is only one. Plants are able to grow on a wide range of substrates when other factors provide compensatory effects. Thus, properties used to separate soil taxa may not be critical to the vegetation of that area.

Land managers should be cautious about attempting to "shortcut" inventories of either vegetational potentials or soils through the process of "assumed correlations." Some useful correlations undoubtedly exist; but they must be developed objectively, tested adequately, and extrapolated with caution.

Climate

Appendix D-2 shows generalized climatic patterns for various habitat types and phases. Most of the data are from U.S. Weather Service stations. The habitat type and phase shown for each station is an estimation of the appropriate climatic climax.

Other climatic data representing specific forest habitat types may be available from Weather Service records or various special studies. Nevertheless, careful evaluation of the site is necessary to determine the appropriate climatic climax. For instance, climatic data from a site supporting an edaphic climax should be interpreted in relation to the nearest expression of a climatic climax, rather than the immediate edaphic climax.

Ecologic Roles of Plant Species

Most plant species express different synecologic roles in different portions of their environmental distribution. A given species can be either a dominant or subordinant, and either climax or seral in different environments. Thus how a species performs on a given site depends on its position within its own environmental distribution as well as the relative positions of its competitors. Relative ecologic expressions of important species in eastern Idaho-western Wyoming forests are presented in several ways.

The occurrence and roles of tree species (appendix B) reflects the relative amplitude and successional status of tree species in the various h.t.'s and phases. This chart provides some of the basic information needed to select and manage the tree species best adapted to a given forest environment. For instance, *Pseudotsuga menziesii* is a major seral species in some *Picea* and *Abies* habitat types but is climax in the *Pseudotsuga* series. In general, the seral species is easier to regenerate following stand disturbance (depending on severity) than the climax species.

The constancy and average coverage data (appendix C) portray the relative amplitude of major forest species and degree of dominance through the environmental spectrum of forest habitat types. Comparison of habitat types using these data from mature stands provides insight to the habitat type classification that is not available in the keys or written descriptions. These tables also condense the vegetal information of each habitat type and reduce the need for elaborate vegetative descriptions.

Timber Productivity

Timber productivity is one of the key management concerns of this study. Site trees were selected to determine the potential height growth of relatively free-growing trees. One site tree of each species was selected for each stand wherever possible. Unfortunately, many stands lacked suitable site trees and some of the stand data incorporated from other studies did not include site index values; as a result, some h.t.'s have a small sample number for timber productivity. Site trees showing marked diameter-growth suppression (diameter growth during a 30-year period less than growth during any subsequent 10-year period) were rejected during analysis of the increment cores. Diameter growth suppression periods of 10- and occasionally 20-year periods were not uncommon in the site trees remaining for productivity analyses. Stagnated trees were not used for productivity estimates. Old-growth trees were used, however, if they occurred in relatively even-aged stands. In most cases only a single site tree per species per stand was used, except for Cooper's (1975) data, which represents an average of 3 to 6 site trees per species per stand. In general, the data are reasonably consistent; comparisons appear to be valid, and the large number of sample sites (982 stands) permits comparison of productivity among habitat types as well as within each habitat type.

Determination of site index from height-age data requires specific procedures for each tree species. The number of years to reach breast height (1.37 m, 4.5 feet) was estimated for species having height-total age site curves but ideally age to breast height should be measured. If a site curve is not available, a curve from another species must be selected as a substitute. Criteria used to determine total age, as well as sources of site index curves and yield capability data for this analysis, are summarized in table 2.

Pinus ponderosa curves (1958) were used to determine *Pseudotsuga* site index rather than Brickell's (1968) *Pseudotsuga* curves, because *P. ponderosa* curve shapes more closely approximate the growth response of *Pseudotsuga* in the Intermountain Region (give closer estimates for different aged site trees in the same stand). This choice of site curves is further strengthened by the fact that in the northern Rocky Mountains *P. ponderosa* yield tables are currently used to determine *Pseudotsuga* yields.

Table 2.—Criteria and sources for determining site index and for estimating yield capability

Species	Estimated years to obtain breast height	Source of site curve[1]	Yield capability (All trees - Figure 4)
PIPO	10	Lynch 1958	Brickell 1970
PSME	10	------------------------Used PIPO curves------------------------	
PICO	10	Alexander 1966	Used LAOC curve[2]
PIEN	([3])	Alexander 1967	Alexander[4]
ABLA	([3])	------------------------Used PIEN curves------------------------	

[1]All site curves with a 100-year index age were converted to a 50-year index age.
[2]Brickell's (1970) curves for PICO and LAOC (trees larger than 5.0 inches) were nearly identical. A new curve (based on all trees) was developed for LAOC from yield data in Schmidt and others (1976). The LAOC curve for all trees appears to be as accurate as any available for estimating PICO yield capability for all trees
[3]Curves based on age at breast height were used.
[4]Data used in a recent yield study (Alexander and others 1975) were provided by Alexander. Site index and mean annual increment from 21 fully-stocked natural stands were used to develop the curve shown in figure 4 (yield capability = 26.0 + 1.84 Site Index (50); R^2 = 0.66).

Alexander's (1967) *Picea engelmannii* curves were used for *Picea* spp. rather than Brickell's (1966) because: (1) Alexander's are based on breast-height age (data available) rather than estimated total age; (2) the curve shapes are more realistic for our region (closer estimates of site index for different aged site trees in the same stand); and (3) yield data related to the curves are available (Alexander and others 1975). Alexander's (1967) *P. engelmannii* curves were also used for other species lacking site index curves, because employing breast-height age avoids the errors inherent in total age estimation.

The site index data (50 years base age) have been summarized by species within habitat types (appendix E-1). Mean site index was calculated whenever three or more values were available. A 95 percent confidence interval (C.I. $= \bar{x} \pm s_{\bar{x}} \cdot t_{0.05}$) for estimation of the tree population mean was computed with five or more values. The confidence interval narrows with decreased variability ($s_{\bar{x}}$ becomes smaller) and increased sample size ($t_{0.05}$ decreases as n, sample size, increases). The same procedure was used for summarizing basal areas of sample stands.

Although site productivity can be compared by site index alone, estimated net yield capability (cubic foot) is more useful. Until managed-stand yield tables are completed, the best approach is to use natural-stand yield tables. As stated by Brickell (1970), "Yield capability, as used by Forest Survey, is defined as mean annual increment of growing stock attainable in fully stocked natural stands at the age of culmination of mean annual increment." In other words, yield capability equals the maximum mean annual increment attainable in fully stocked natural stands.

The curves used to estimate yield capability from site index are presented in figure 31. Yield capability values are based on cubic feet of all trees (>0.5 inch d.b.h.). The *Larix occidentalis* (*LAOC*) curve was derived from Schmidt and others (1976). (Brickell's 1970 curve for this species was only for trees greater than 5.0 inches in diameter.) The *Larix* curve was also used for *Pinus contorta* because Brickell's (1970) curves (trees >5.0 inches) are almost identical for the two species, and because natural stand yield data have not been published for *Pinus contorta*.

The *Picea* curve was derived from original data used in developing managed stand yield tables (Alexander and others 1975). We calculated mean annual increment for all trees for 21 of Alexander's fully stocked natural stands near the age of culmination of mean annual increment (ages from 97 to 165 years). A linear regression of yield capability on Alexander's (1967) site index was conducted, converted to site index at base-age 50, and plotted in figure 31. [Yield Capability = -26.0 + (1.84 X 50-year site index) R^2 = 0.66]. The other curves were developed by Brickell (1970) from natural-stand yield tables.
The spread in these curves (fig. 31) indicates that natural-stand yield capability for a given site index varies by species. This illustrates the importance of using species-specific curves for estimating productivity. Current estimates of yield capability (in cubic feet/acre/year) for each habitat type are shown in appendix E-2. Procedures used to develop these estimates were:

1. Yield capability was estimated for each site tree from appropriate species curves according to the criteria in table 2. Values were plotted by species within habitat types and phases for a visual display of distribution.

2. Mean yield capability for all site trees in each habitat type was calculated and cutoff points were established to approximate 90 percent of the range of our data.

3. For habitat types where stockability appears to limit productivity, a stockability factor was developed. Basal area data (appendix E-1) for plots in these types were compared with Meyer's (1938) basal area data for *P. ponderosa* for fully stocked "normal" stands, following the approach of MacLean and Bolsinger (1973). From these calculations and additional observations, an average mean stockability factor was determined for several habitat types. This factor was multiplied by yield capability for a given site index to determine the adjusted yield capability. A factor of 0.05 was used to adjust the estimated range of productivity for these habitat types.

These current best estimates (appendix E-2) portray both relative productivity of habitat types and the range of productivity within a habitat type. From these estimates, it

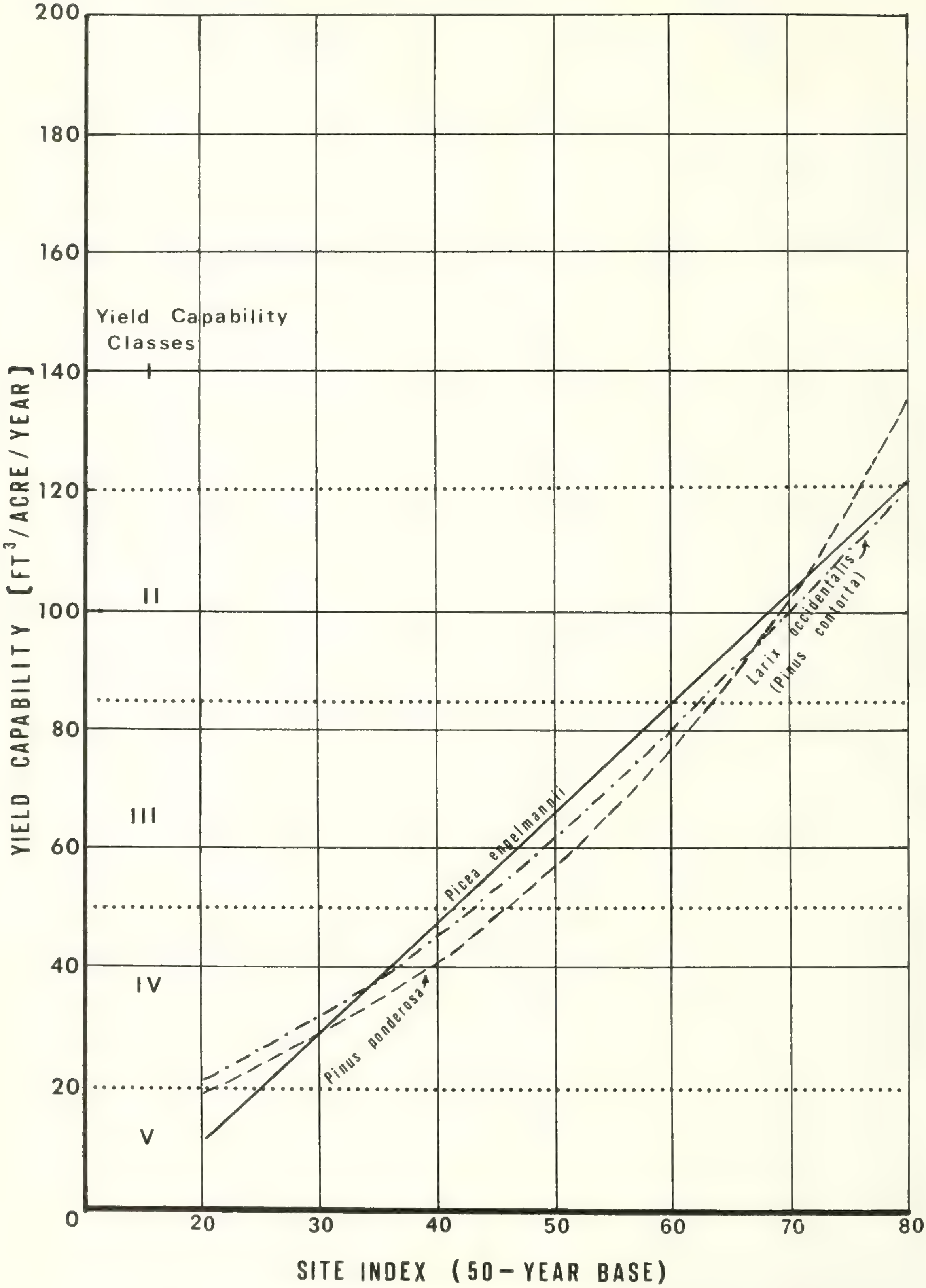


Figure 31.—Yield capability of fully stocked natural stands in relation to site index (revised from Pfister and others 1977).

is possible to assign a ranking or qualitative rating of potential timber productivity of natural stands for use in planning.

As Daubenmire (1976) emphasized, natural vegetation serves as a convenient indicator of productivity over large areas of land. But, productivity within habitat types (appendix E-2) often varies substantially. The following list explains this variability and offers suggestions for reducing it.

1. Site-index curves were used to obtain productivity estimates from yield tables. Different height-growth patterns undoubtedly occur on different sites just as they have been shown to vary with habitat type (Daubenmire 1961); however, data to account for this variation are not available.

2. Yield tables and site curves have not been developed for all species or all growth regions, making extrapolation necessary and tenuous at times.

3. Yields of mixed species stands can be estimated by several individual species yield tables. We found that a range in yield capability was common in individual stands, depending on the species used for estimation.

4. Some variability in productivity within a natural classification system, such as habitat types, is expected. The habitat type classification is based not on species rates of growth, but on their ability to mature and reproduce under competition, which encompasses all their individual strategies for survival. The correlation between competitive strategies and productivity are imperfect at best. For instance, in a given habitat type, large trees on one site may draw on a deep water table and grow better than the same species on another site, or grow relatively better than associated tree seedlings and undergrowth which depend on moisture close to the surface.

5. Where a more accurate estimate of productivity is needed for local areas, we recommend taking additional site-index samples.

6. It has been suggested that productivity estimates for habitat types could be made more predictive by incorporating classifications of soils, topography, or climate. To a limited extent, climatic or geographic differences have been recognized and accounted for, as in the east-west (of Continental Divide) dichotomy of the Montana classification (Pfister and others 1977) and in the partitioning of Idaho into several physiographic regions (Steele and others 1981). Productivity (site indices and yield capability) seems to vary significantly within the same habitat type between east and west side Montana sites. Also, a number of habitat types common to central Idaho, Montana, and our study area show higher productivities in central Idaho. Differences in productivity within a habitat type due to topography, soils, or parent material are apparent in some local areas. Here again if accurate estimates are needed locally, one could stratify sites, for example, by parent materials (calcareous versus noncalcareous). But, because of the limitations of existing site index curves and yield tables, further refinements of productivity data for large areas would benefit more from increased precision in methods of measuring productivity.

7. The yield of natural stands by habitat type could be estimated more precisely by direct measurements of volume growth, rather than by using site index to enter a yield table based on averages. This approach would require analysis of existing timber inventory plots representing maximum growth potential or new field measurements.

8. Stand growth models (Stage 1973, 1975) utilize growth coefficients based on habitat types. These models add a new dimension to yield prediction, provide the basis for developing managed-stand yield tables, and should eventually improve our knowledge of productivity within and between habitat types.

Zonal Relationships of Habitat Types

Just as individual species occur in a predictable sequence with changing environments, h.t.'s also display predictable patterns in local areas. On a larger scale, the sequence of h.t.'s will vary through additions or omissions, but their relative positions should remain constant. Thus *Pseudotsuga* h.t.'s normally occur in warmer and drier environments than *Abies lasiocarpa* h.t.'s, but *Picea* h.t.'s may occur between the two series or may be absent. This rule applies to patterns of individual h.t.'s and phases as well as series.

In order to demonstrate the relative positions of eastern Idaho-western Wyoming h.t.'s, schematic diagrams (figs. 32-37) are presented for characteristic localities. These diagrams are frustrated by the difficulty of depicting a three-dimensional landscape or a multidimensional environment in two dimensions, and so, are not literally accurate. Also, the number of h.t.'s in any given transect may vary from the general diagram for that particular area. Note particularly that habitat types of alluvial benches or lands bordering stream bottom-lands are largely omitted. Nevertheless, they do present a generalized concept of habitat type zonation in different geographic areas.

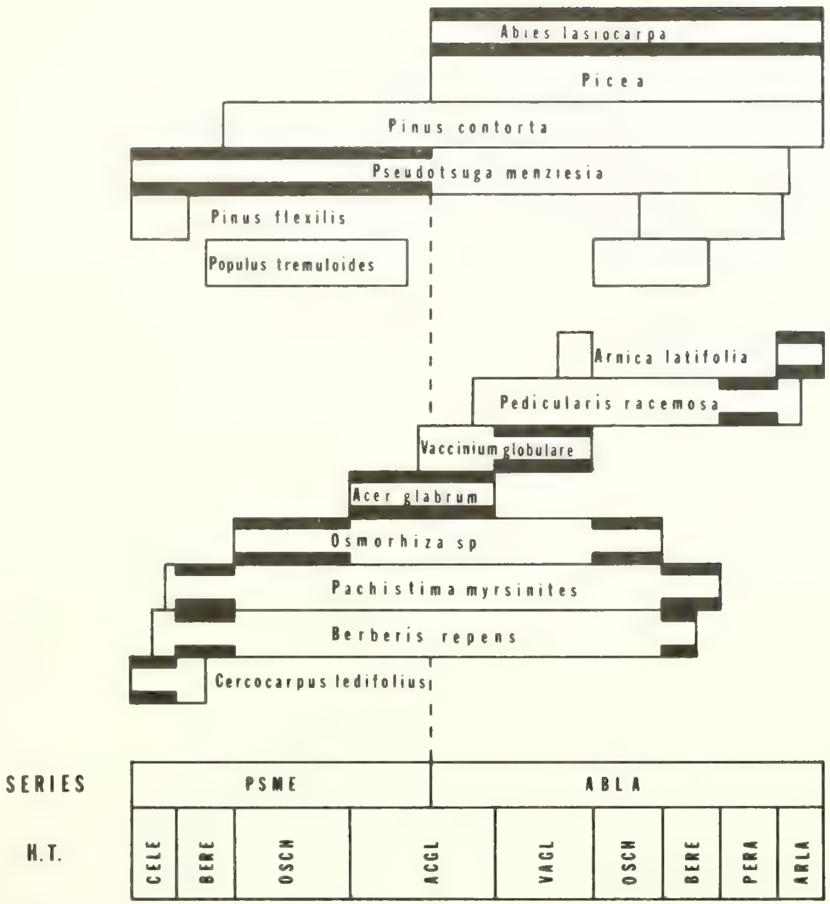


Figure 32.—General relationship of forest vegetation near Soda Springs, Idaho.

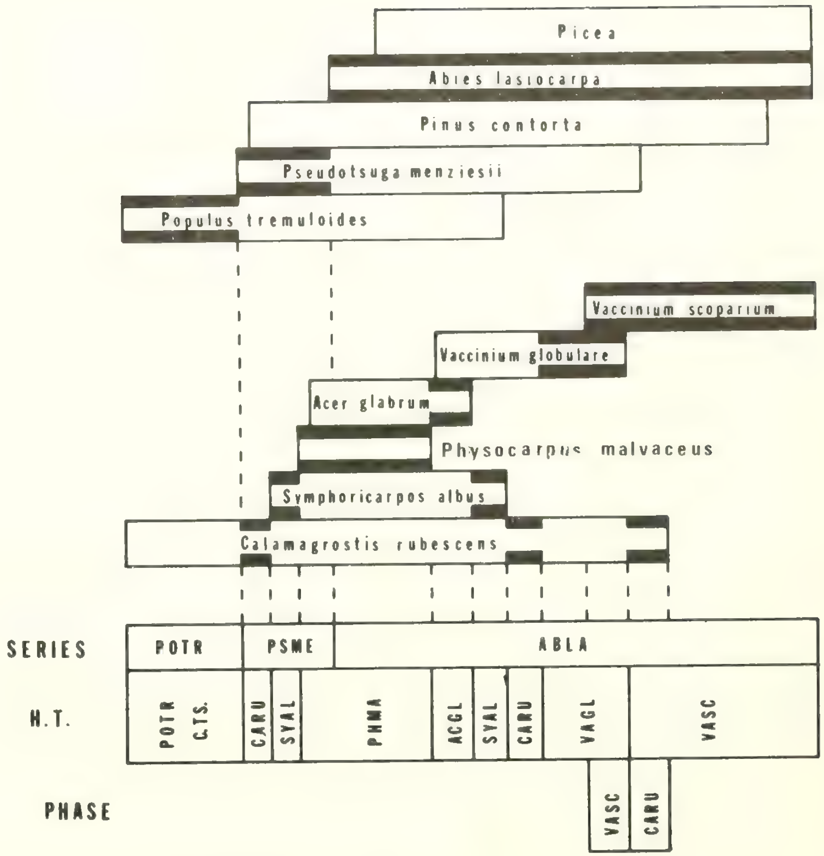


Figure 33.—General relationship of forest vegetation near Alpine, Wyoming.

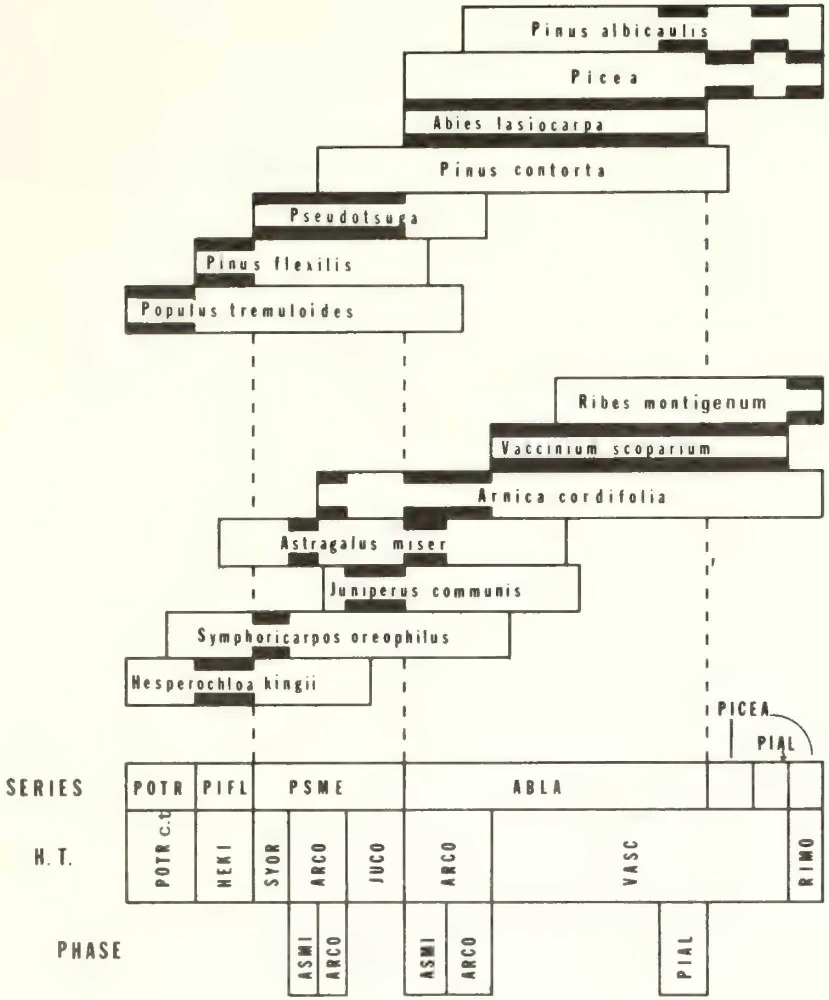


Figure 34.—General relationship of forest vegetation near Pinedale, Wyoming.

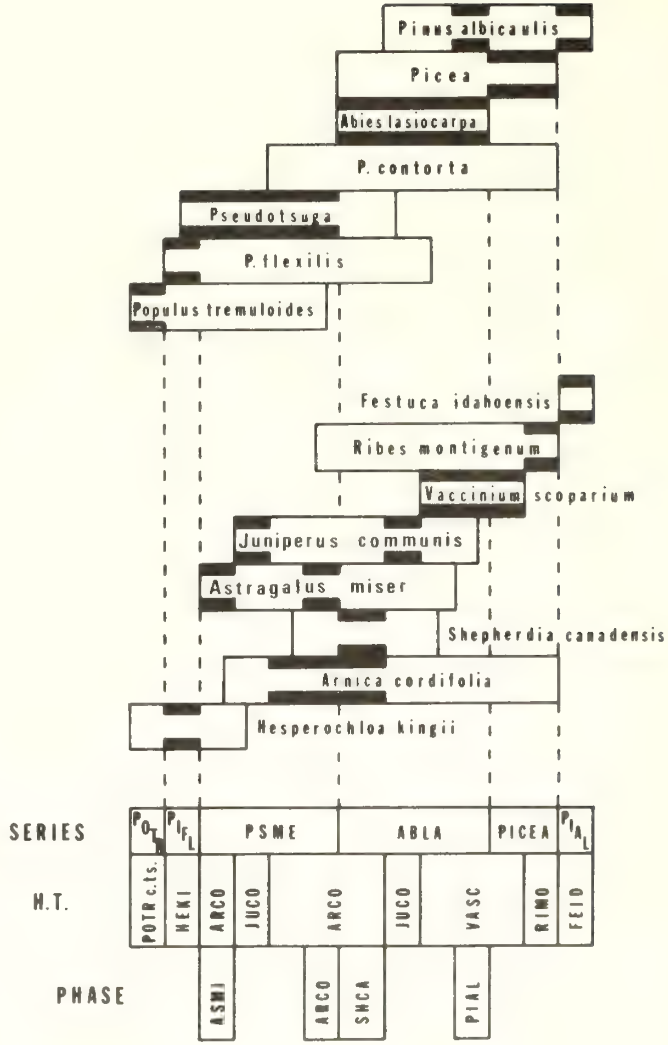


Figure 35.—General relationship of forest vegetation in the Wind River Range near Dubois, Wyoming.

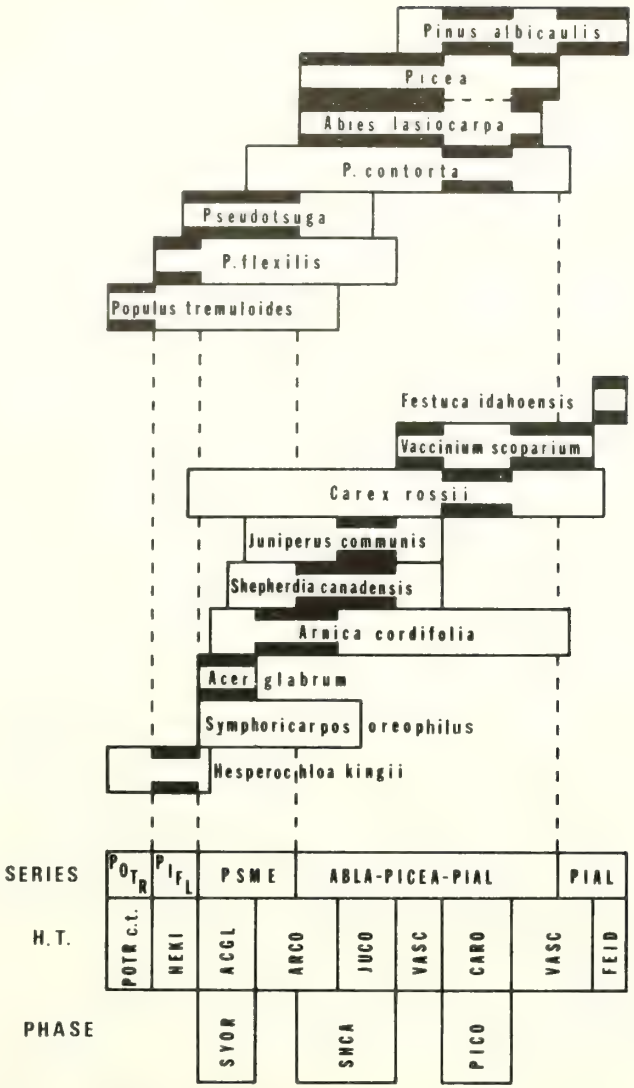


Figure 36.—General relationship of forest vegetation near Lander, Wyoming.

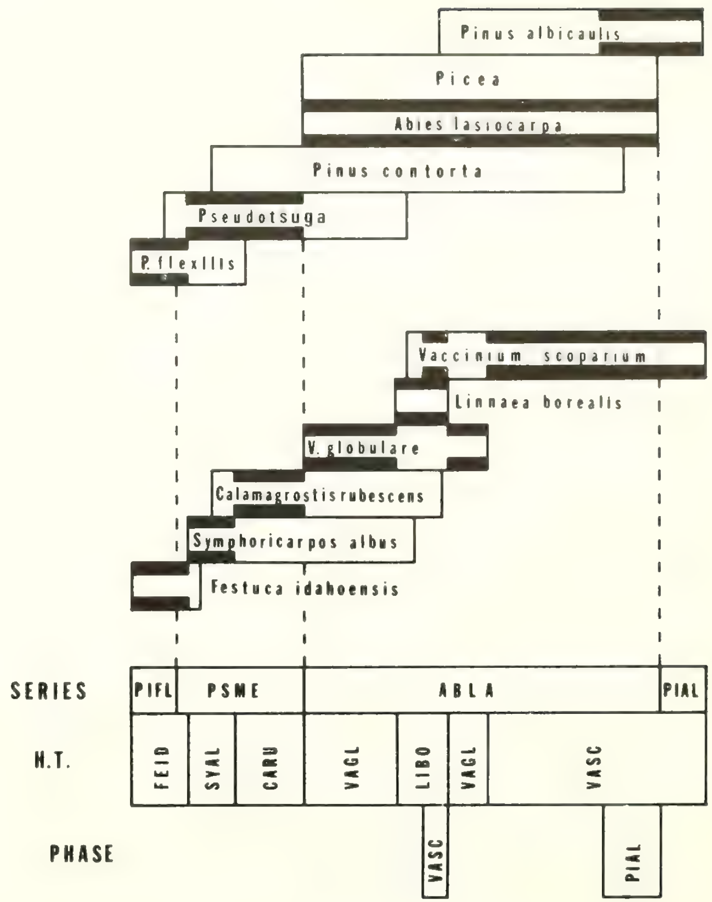


Figure 37.—General relationship of forest vegetation west of Cody, Wyoming.

₹elationship to Previous Habitat Type Classifications in the Study Area

ıs in any classification procedure, increased accuracy is ıbtained through a series of approximations, with each tep adding refinement (Poore 1962). This classification ofers several refinements to the pioneering work of Reed 1969, 1976) and Cooper (1975) in our study area. It also epresents a few revisions to the preliminary classificaions for this area (Steele and others 1974 unpubl., 1977 ınpubl., 1979 unpubl.; Henderson and others 1976 unpubl.) igure 38 illustrates the relationships of these clasifications in terms of the variation encompassed by each ı.t. and phase.

JSE OF THE CLASSIFICATION

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'his classification attempts to provide a natural stratificaion of forest lands in terms of potential vegetational deelopment. It is designed to reflect the combined forces ıf the environment upon a given site and discounts the emporary alterations of disturbance. Although the actual ınvironmental parameters of a vegetal unit are often unːnown, the major importance of this classification lies in he knowledge of the relative positions of the vegetal ınits. As R. and J. Daubenmire (1968) have pointed out '...that system may be considered the closest to a natural ɔne that allows the most predictions about a unit from a nere knowledge of its position in the system".

This classification reflects about 6 years of sampling varous portions of the study area, developing preliminary drafts for some of these areas, and field testing by foresters. Suggested revisions were analyzed and often ncorporated. These inputs have substantially improved the classification but since this classification was developed through a series of approximations, it should always remain open to further refinement.

Use of Habitat Types

Layser (1974) and Pfister (1976) have outlined potential values of habitat types in resource management. Perhaps the most important use is a land stratification system—designating land areas with approximately equivalent environments or biotic potential—thereby providing a tool for cataloging research results, administrative study results, accumulated field observations, and intuitive evaluations. The habitat type classification provides a basis for predicting the response of vegetation to management related activities. One caution, however, is that habitat types are **not** a panacea for all decisionmaking or interpretations. Habitat types **will** complement information on existing vegetation soils, outdoor recreation, socioeconomic conditions, hydrology, and wildlife, and will aid development of more intensive land-management planning and practices. They do not provide a substitute for maps or classifications of existing vegetation, such as forest cover types.

Some of the current and potential uses of habitat types include:

1. Communication—provide a common framework for site recognition and interdisciplinary activities.

2. Timber management—stratification of seed source, species selection for planting, cutting and regeneration methods, assessing relative timber productivity.

3. Range and wildlife management—assessing relative forage production and wildlife habitat values.

4. Watershed—estimating relative plant available moisture levels and evapotranspiration rates; recognizing areas of heavy snowpack, high water tables, etc.

5. Recreation—assessing suitability for various types of recreational use, impacts of recreational use on the plant communities and sites, and esthetic recovery rates following stand disturbances.

6. Forest protection—categorization of fuel buildup, fuel management, and the natural role of fire (frequency and intensity of burns); assessment of susceptibility to various insects and diseases.

7. Natural area preservation—help insure that the environmental spectrum is adequately represented in research natural areas.

8. Research—stratification tool for designing studies; reporting results in a format suitable for appropriate extrapolation.

Some management implications are discussed in the descriptions of the habitat types in this report. The appendix data can provide additional implications through interpretation by appropriate specialists. Field personnel can also document repeated observations to help expand our knowledge of the vegetation reactions on specific habitat types.

Wind River Mtns. Reed 1969	S. Sawtooth N.F. (in) Steele and others 1974 unpubl.	N. W. Wyoming & adj. Montana & Idaho. Cooper 1975	Wind River Mtns. Reed 1976	N. W. Utah & adj. Idaho. Henderson and others 1976 unpubl.	E. Idaho-W. Wyoming Preliminary classification. Steele and others 1977	E. Idaho-W. Wyoming Forest Habitat Types Steele and others 1979	E. Idaho-W. Wyoming Forest Habitat T[illegible]
		PSME-PIFL/HEKI(in part)			PIFL/HEKI	PIFL/HEKI	PIFL/HEKI
PSME/SYOR(in part)			PSME/SYOR(in part)	PIFL/ARTR(in part)	PIFL/FEID, FEID	PIFL/FEID, FEID	[illegible]
				PIFL/CELE	PIFL/CELE	PIFL/CELE	[illegible]
PSME/SYOR(in part)			PSME/SYOR(in part)		PIFL/JUCO	PIFL/JUCO	[illegible]
	PSME/SYOR, FRVI(in part) PSME/SYOR, SYOR	PSME/SYAL,SYAL(in part)			PSME/SYOR	PSME/SYOR	PSME/[illegible]
PSME/SYOR(in part)			PSME/SYOR(in part)		PSME/ARCO,ARCO	PSME/ARCO,ARCO	[illegible]
					PSME/ARCO,ASMI	PSME/ARCO,ASMI	PSME/[illegible],ASMI
	PSME/CELE	PSME-PIFL/HEKI(in part)		PSME/CELE	PSME/CELE	PSME/CELE	PSME/CELE
PSME/SYOR(in part)		PSME/SYAL,SYAL(in part)	PSME/SYOR(in part)		PSME/JUCO(in part)	PSME/JUCO	[illegible]
	PSME/SYOR, FRVI(in part)				PSME/BERE(in part)	PSME/BERE,SYOR	PSME/[illegible]
PSME/SYOR(in part)		PSME/VAGL(in part)	PSME/SYOR(in part)		PSME/JUCO(in part)	PSME/BERE,JUCO	PSME/[illegible]
	PSME/BERE	PSME/SYAL,SYAL(in part)		PSME/BERE	PSME/BERE(in part)	PSME/BERE,BERE	PSME/BERE,BERE
	PSME/CARU, BERE	PSME/SYAL,CARU(in part)		PSME/CARU	PSME/CARU,PAMY	PSME/CARU,PAMY	PSME/CARU,[illegible]
	PSME/CARU, CARU	PSME/CARU(in part)			PSME/CARU,CARU	PSME/CARU,CARU	PSME/[illegible]
		PSME/SYAL,CARU(in part)			PSME/SPBE,CARU	PSME/SPBE,CARU	PSME/SPBE,[illegible]
					PSME/SPBE,SPBE	PSME/SPBE,SPBE	PSME/SPBE,SPBE
	PSME/OSCH	PSME/SYAL,SYAL(in part)		PSME/OSCH	PSME/OSCH	PSME,OSCH	PSME,OSCH
					(eastern PSME/SYAL variant)	PSME/SYAL,SYAL	PSME/SYAL,SYAL
		PSME/VAGL(in part)			PSME/VAGL	PSME/VAGL,VAGL	PSME/VAGL,VAGL PSME/[illegible]
PSME/SYOR(in part)			PSME/SYOR(in part)		PSME/ACGL,SYOR	PSME/ACGL,SYOR	PSME/BERE,[illegible]
		PSME/VAGL(in part)		PSME/ACGL	PCME/ACGL,PAMY	PSME/ACGL,PAMY	PSME/ACGL,PAMY
	PSME/PHMA	PSME/PHMA		PSME/PHMA	(eastern PSME/PHMA variant)	PSME/PHMA,PAMY	PSME/PHMA,PAMY
						PSME/PHMA,PSME	PSME/PHMA,PSME
					PIEN/HYRE	PICEA/HYRE	PIEN/HYRE
						PICEA/ARCO	PIEN/[illegible]
ABLA/PYSE(in part)			ABLA/PONE(in part)		PIEN/RIMO	PICEA/RIMO	PIEN/RIMO
						PICEA/JUCO	[illegible]
PIEN/VASC(in part)			PIEN/VASC(in part)		PIEN/VASC	PICEA/VASC	[illegible]
		PICEA-ABIES/LIBO			PIEN/LIBO	PICEA/LIBO	PIEN/LIBO
		PICEA-ABIES/GATR			PIEN/GATR	PICEA/GATR	PIEN/GATR
					PIEN/CADI	PICEA/CADI	PIEN/[illegible]
						PICEA/CALE	PIEN/CALE
		PICEA/EQAR			PIEN/EQAR	PICEA/EQAR	PIEN/EQAR

(con.)

Wind River Mtns. Reed 1969	S. Sawtooth N.F. (in) Steele and others 1974 unpubl.	N. W. Wyoming & adj. Montana & Idaho Cooper 1975	Wind River Mtns. Reed 1976	N. W. Utah & adj. Idaho. Henderson and others 1976 unpubl.	E. Idaho-W.Wyoming Preliminary classification. Steele and others 1977	E.Idaho-W. Wyoming Forest Habitat Types Steele and others 1979	E. Idaho-W. Wyoming Forest Habitat Types.
		ABLA/CACA			ABLA/CACA, CACA	ABLA/CACA, CACA	ABLA/CACA,CACA
				ABLA/ACGL(in part)	ABLA/ACRU	ABLA/ACRU	ABLA/ACRU
				ABLA/PHMA	ABLA/PHMA	ABLA/PHMA	ABLA/PHMA
				ABLA/ACGL(in part)	ABLA/ACGL,PAMY	ABLA/ACGL,PAMY	ABLA/ACGL,PAMY
ABLA/PYSE(in part)		PICEA-ABIES/LIBO			ABLA/LIBO,VASC	ABLA/LIBO,VASC	ABLA/LIBO,VASC
					ABLA/LIBO, LIBO	ABLA/LIBO,LIBO	ABLA/LIBO,LIBO
		ABLA/VAGL		ABLA/VAGL	ABLA/VAGL, VASC	ABLA/VAGL,VASC	ABLA/VAGL,VASC
					ABLA/VAGL,PAMY	ABLA/VAGL,PAMY	ABLA/VAGL,PAMY
					ABLA/VAGL,VASC	ABLA/VAGL,VAGL	ABLA/VAGL,VAGL
		ABLA/VASC,PICO			ABLA/VASC,CARU	ABLA/VASC,CARU	ABLA/VASC,CARU
PIAL-PIFL/PODI(in part)		ABLA/VASC,PIAL	PIAL/VASC(in part)				ABLA/VASC,PIAL
PIEN/VASC(in part) ABLA/PYSE(in part)		ABLA/VASC,PICO	PIEN/VASC(in part) ABLA/PONE(in part)	ABLA/VASC	ABLA/VASC,VASC	ABLA/VASC,VASC	ABLA/VASC,VASC
				ABLA/ARLA	ABLA/ARLA	ABLA/ARLA	ABLA/ARLA
					ABLA/SYAL	ABLA/SYAL	ABLA/SYAL
ABLA/PYSE(in part)			ABLA/PONE(in part)		ABLA/THOC	ABLA/THOC	ABLA/THOC
	ABLA/OSCH	ABLA/THOC,THOC		ABLA/OSCH	ABLA/OSCH,PAMY	ABLA/OSCH,PAMY	ABLA/OSCH,PAMY
					ABLA/OSCH,OSCH	ABLA/OSCH,OSCH	ABLA/OSCH,OSCH
		ABLA/VAGL,SPBE			ABLA/SPBE	ABLA/SPBE	ABLA/SPBE
	ABLA/CARU,BERE	ABLA/CARU		ABLA/CARU	ABLA/CARU,PAMY	ABLA/CARU,PAMY	ABLA/CARU,PAMY
	ABLA/CARU,CARU				ABLA/CARU,CARU	ABLA/CARU,CARU	ABLA/CARU,CARU
PSME/SYOR(in part)	ABLA/BERE	ABLA/THOC,ARCO ABLA/VAGL,SPBE	PSME/SYOR(in part)	ABLA/BERE	ABLA/BERE	ABLA/BERE	ABLA/BERE,BERE
ABLA/PYSE(in part)			ABLA/PONE(in part)		ABLA/JUCO	ABLA/JUCO	ABLA/JUCO
	ABLA/RIMO			ABLA/RIMO	ABLA/RIMO	ABLA/RIMO	ABLA/RIMO,RIMO
				ABLA/PERA	ABLA/PERA	ABLA/PERA	ABLA/PERA
ABLA/PYSE(in part)		ABLA/THOC,ARCO	ABLA/PONE(in part)		ABLA/ARCO,ARCO	ABLA/ARCO,PIEN	ABLA/ARCO,PIEN
					ABLA/ARCO,ASMI	ABLA/ARCO,SHCA	ABLA/ARCO,SHCA
						ABLA/ARCO,ASMI	ABLA/ARCO,ASMI
					ABLA/ARCO,ARCO	ABLA/ARCO,ARCO	ABLA/ARCO,ARCO
	ABLA/CARO			ABLA/CARO	ABLA/CARO	ABLA/CARO	ABLA/CARO
							ABLA/RIMO,PIAL
PIAL-PIFL/PODI(in part)		PIAL/VASC	PIAL/VASC(in part)			PIAL/VASC	PIAL/VASC
		PIAL/CAGE(in part)				PIAL/CAGE	PIAL/CAGE
						PIAL/JUCO,SHCA	PIAL/JUCO,SHCA
PICO communities			PICO/PONE		PIAL h.t.s.	PIAL/JUCO,JUCO	PIAL/JUCO,JUCO
		PIAL/CAGE,PICO(in part)				PIAL/CARO,PICO	PIAL/CARO,PICO
PIAL-PIFL/PODI(in part)		PIAL/CAGE,PIAL(in part)	PIAL/VASC(in part)			PIAL/CARO,CARO	PIAL/CARO,CARO
						PIAL/FEID	PIAL/FEID

Figure 38.—Relationship to previous habitat type classification in eastern Idaho-western Wyoming.

Mapping

Habitat type maps have become an important management tool in the Northern Region of the USDA Forest Service (Deitschman 1973; Stage and Alley 1973; Daubenmire 1973). They provide a permanent record of habitat type distribution on the landscape and a basis for acreage estimates for land management.

Maps may be made at various scales and degrees of accuracy, depending upon objectives. For activities such as research studies and project planning, maps should be accurate and detailed; each phase of a habitat type should be delineated, especially for research studies. The map scale should range from 4 to 8 inches per mile. At broader levels of planning such as National Forests, map accuracy and detail may be less and mapping efforts may be less extensive. Habitat types are often the finest subdivisions shown, and map scale can range from 1/2 to 2 inches per mile.

Still broader levels of mapping may be required for regional needs (selection of powerline corridors, State or regional planning); these may employ scales of 1/4 to 1/2 inch per mile, and may depict only habitat type groups or series. These should be synthesized from more detailed habitat type maps whenever the latter are available.

Selecting a mapping approach and appropriate scale to produce an acceptable map must be based on the following: (1) anticipated use of the map, (2) accuracy level required, (3) availability of adequately trained personnel, and (4) amount of time and financial support available to achieve the specified accuracy level.

At scales of 4 to 8 inches per mile, the habitat types or phases are useful as the mapping units, accepting inclusions (up to 15 percent) of other types too small to map separately. In complex topography and at smaller map scales, special mapping units must be developed, which may be called "complexes" or "mosaics". Such mapping unit complexes must be defined for each area being mapped, rather than on a preconceived grouping. The amount and relative positions of habitat types and phases within a complex must be specified because the management interpretations of a mapping unit are tied to the taxonomic units—series, habitat type, and phase.

Regardless of the mapping scale used, any field reconnaissance should identify stands to the phase level. Later, the phases can be grouped to accommodate specific purposes of the map, but broader mapping units cannot be refined after the field work is completed. The amount and location of field reconnaissance should also be specified on the map or in a report for users of the map. Finally, the map accuracy should be estimated and checked to maintain quality control in management application.

Grouping

Because this classification system for potential vegetation is hierarchical, it can be used at various levels of differentiation for various purposes. Collecting and recording of field data (vegetation inventories) should be done with enough detail to allow for determination of habitat type and phase and should be recorded in a standard format such as a checklist (appendix F). Using this approach is only slightly more time-consuming than taking cruder fiel data, and it enhances the value of the data as well as the comprehension of the investigator and his professional credibility. Above all, it provides flexibility in the ultimate use of the data. In contrast, if data are collected at the habitat type group level, rearrangement, or more detailed analysis is not possible.

In a given forested area, only a small percentage of all the forest habitat types and phases will occur. Moreover, some of these will be so minor in extent or so poorly developed that once their presence is documented they need not enter into most broad scale forest management considerations. This leaves a relatively small number of habitat types to be identified (and mapped) as such. After the distribution patterns of all the habitat types in a given area are identified, the types can be arranged in logical categories to facilitate resource planning and public presentations.

Many h.t.'s and phases can be grouped according to similar ecologic and geographic characteristics. Some of these groups have similar stand structure or edaphic characteristics. Others have similar responses to disturbance (tall seral shrubs) or similar timber productivities on a local basis. Where management implications are similar, it may be desirable to consider an entire series, such as the *Pinus flexilis* series as one group. Conversely, where management considerations contrast strongly even at the phase level, as in the phases of *PSME/BERE*, it may be desirable to split a habitat type in the grouping process. One example of grouping based on similar ecologic and geographic characteristics is the following:

PINUS FLEXILIS Series

PSME/SYOR; PSME/BERE, SYOR phase

PSME/ARCO; PSME/JUCO; PSME/BERE, JUCO phase

PSME/BERE, CAGE phase; PSME/CARU, CARU phase; PSME/SPBE, CARU phase

PSME/SPBE, SPBE phase; PSME/SYAL, SYAL phase

PSME/ACGL, PAMY phase; PSME/PHMA, PAMY phase, ABLA/ACGL; ABLA/PHMA

PIEN/HYRE; PIEN/ARCO; PIEN/JUCO

PIEN/CADI; PIEN/CALE; PIEN/EQAR

ABLA/LIBO; ABLA/VAGL

ABLA/OSCH; ABLA/BERE

ABLA/CACA, ABLA/STAM

ABLA/JUCO; ABLA/ARCO, ARCO phase

ABLA/VASC, CARU phase; ABLA/CARU

ABLA/VASC, PIAL phase; PIEN/VASC; PIAL/VASC

PIAL/JUCO; PIAL/CARO

)ther bases for groupings may be useful for various spec-
alists in resource management. Again, it is important to
larify that such groupings, if used at all in preference to
abitat types alone, should be made only **after** a thorough
nventory has been completed at the habitat type level.
ny group category used should include a record of the
elative amounts of each habitat type (or phase) included
herein to document the basis for general statements
bout the grouping.

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APPENDIX A. NUMBER OF SAMPLE STANDS BY HABITAT TYPE, PHASE AND VICINITY IN EASTERN IDAHO-WESTERN WYOMING[1]

ST = Sawtooth National Forest
C = Caribou National Forest
BT = Bridger-Teton National Forest
T = Targhee National Forest
TP = Teton National Park
YP = Yellowstone National Park
SH = Shoshone National Forest
WR = Wind River Reservation

	VICINITY								
HABITAT TYPE, PHASE	ST	C	BT	T	TP	YP	SH	WR	TOTAL
***PINUS FLEXILIS* SERIES**									
PIFL/HEKI	.	.	3	.	.	.	12	7	22
PIFL/FEID, FEID	.	.	1	.	.	.	1	1	3
PIFL/CELE	.	3	.	.	.	.	.	.	3
PIFL/JUCO	.	.	.	.	.	.	4	2	6
									34
***PSEUDOTSUGA MENZIESII* SERIES**									
PSME/SYOR	.	.	8	1	.	1	1	3	14
PSME/ARCO, ARCO	.	.	7	.	.	1	3	10	21
PSME/ARCO, ASMI	.	.	1	.	.	.	.	2	3
PSME/CELE	.	5	1	2	.	.	.	.	8
PSME/JUCO	.	.	2	1	.	1	5	12	21
PSME/BERE, SYOR	.	3	.	.	.	.	.	.	3
PSME/BERE, JUCO	.	.	2	.	.	.	2	2	6
PSME/BERE, BERE	4	15	3	.	.	.	2	.	24
PSME/CARU, PAMY	5	5	1	2	.	.	.	.	13
PSME/CARU, CARU	2	4	5	11	.	5	.	.	27
PSME/SPBE, CARU	.	.	1	6	2	.	1	.	10
PSME/SPBE, SPBE	.	.	2	3	1	2	1	.	9
PSME/OSCH	4	16	.	4	.	.	.	.	24
PSME/SYAL, SYAL	.	.	7	4	.	3	4	.	18
PSME/VAGL, VAGL	.	.	.	3	.	.	.	.	3
PSME/ACGL, PAMY	.	13	2	7	1	.	1	1	25
PSME/PHMA, PAMY	3	4	6	4	.	.	.	.	17
PSME/PHMA, PSME	.	.	.	.	.	1	4	.	5
									251
***PICEA ENGELMANNII* SERIES**									
PIEN/HYRE	.	.	.	.	.	1	3	7	11
PIEN/ARCO	.	.	.	.	.	.	5	12	17
PIEN/RIMO	.	.	2	.	.	.	1	2	5
PIEN/JUCO	.	.	1	.	.	.	3	17	21
PIEN/VASC	.	.	7	.	.	.	2	4	13
PIEN/LIBO	.	.	1	.	.	4	3	.	8
PIEN/GATR	.	.	2	1	.	1	4	.	8
PIEN/CADI	.	.	1	1	.	.	2	.	4
PIEN/CALE	.	.	2	.	.	.	2	6	10
PIEN/EQAR	.	.	6	1	.	.	3	.	10
									107

(con.)

HABITAT TYPE, PHASE	VICINITY								
	ST	C	BT	T	TP	YP	SH	WR	TOTAL
***ABIES LASIOCARPA* SERIES**									
ABLA/CACA, CACA	.	.	1	1	.	1	1	.	4
ABLA/ACRU	.	3	9	2	2	2	.	.	18
ABLA/PHMA	.	2	5	1	.	.	.	.	8
ABLA/ACGL, PAMY	.	13	3	7	.	.	.	.	23
ABLA/LIBO, VASC	.	.	6	.	.	4	1	.	11
ABLA/LIBO, LIBO	.	.	7	.	.	2	6	.	15
ABLA/VAGL, VASC	.	.	5	2	.	3	.	.	10
ABLA/VAGL, PAMY	.	22	10	11	7	1	.	.	51
ABLA/VAGL, VAGL	.	.	.	1	2	1	.	.	4
ABLA/VASC, CARU	.	1	4	.	.	.	.	.	5
ABLA/VASC, PIAL	.	.	9	1	2	5	10	.	27
ABLA/VASC, VASC	.	4	39	1	.	5	7	5	61
ABLA/ARLA	.	17	1	1	.	1	1	.	21
ABLA/SYAL	.	1	8	2	.	.	.	.	11
ABLA/THOC	.	.	5	4	.	6	.	1	16
ABLA/OSCH, PAMY	.	6	3	.	.	.	.	.	9
ABLA/OSCH, OSCH	8	15	.	.	.	.	.	.	23
ABLA/SPBE	.	1	7	2	1	.	.	.	11
ABLA/CARU, PAMY	1	2	1	2	.	.	.	.	6
ABLA/CARU, CARU	3	6	6	.	.	1	.	.	16
ABLA/BERE, BERE	3	30	13	1	.	.	1	.	48
ABLA/JUCO	.	.	1	.	.	.	6	1	8
ABLA/RIMO, RIMO	4	.	4	1	.	.	1	.	10
ABLA/RIMO, PIAL	.	.	8	.	.	.	.	.	8
ABLA/PERA	.	10	7	1	.	.	.	.	18
ABLA/ARCO, PIEN	.	.	7	.	.	.	5	.	12
ABLA/ARCO, SHCA	.	.	3	.	.	.	5	2	10
ABLA/ARCO, ASMI	.	.	6	.	.	.	5	.	11
ABLA/ARCO, ARCO	.	1	14	1	.	.	.	1	17
ABLA/CARO	3	.	1	.	.	.	.	.	4
									496
***PINUS ALBICAULIS* SERIES**									
PIAL/VASC	.	.	3	.	1	1	2	2	9
PIAL/CAGE	.	.	.	2	.	1	.	.	3
PIAL/JUCO, SHCA	.	.	.	.	.	.	3	.	3
PIAL/JUCO, JUCO	.	.	2	.	.	.	2	11	15
PIAL/CARO, PICO	.	.	2	1	.	4	9	1	17
PIAL/CARO, CARO	.	.	.	.	.	1	.	2	3
PIAL/FEID	.	.	.	.	.	.	1	2	3
									53
Unclassified Stands	1	2	14	2	.	4	10	7	40
									40
Total	41	204	288	98	19	63	145	123	981

[1]h.t. descriptions may reference locations based on reconnaissance data not included in this table.

APPENDIX B. OCCURRENCE AND ROLES OF TREE SPECIES BY HABITAT TYPES

Occurrence of tree species by habitat type, showing successional status as interpreted from eastern Idaho and western Wyoming reconnaissance plot data.

C = major climax species S = major seral species a = accidental
c = minor climax species s = minor seral species ( ) = only in certain areas of h.t.

HABITAT TYPE, PHASE	POTR	JUSC	PIFL	PSME	PICO	PIPU	PIEN	ABLA	PIAL
PIFL/HEKI	a	(c)	C	C	a	.	.	.	.
PIFL/FEID, FEID	.	(c)	C	C	.	.	.	.	.
PIFL/CELE	.	(c)	C	C	.	.	.	.	.
PIFL/JUCO	.	a	C	C	(c)	.	a	.	.
PSME/SYOR	a	(c)	(c)	C	.	.	.	.	.
PSME/ARCO, ARCO	a	(s)	s	C	(s)	.	a	.	.
PSME/ARCO, ASMI	a	(s)	s	C	a	.	.	.	.
PSME/CELE	.	(C)	(c)	C	.	.	.	.	.
PSME/JUCO	a	(s)	s	C	(s)	.	a	a	.
PSME/BERE, SYOR	.	a	a	C	.	.	.	.	.
PSME/BERE, JUCO	S	.	s	C	S	.	.	.	.
PSME/BERE, BERE	(S)	(s)	(s)	C	(S)	.	.	a	.
PSME/CARU, PAMY	(S)	a	a	C	(S)	.	.	a	.
PSME/CARU, CARU	(S)	a	(s)	C	(S)	.	.	a	.
PSME/SPBE, CARU	a	.	a	C	(S)	.	.	.	.
PSME/SPBE, SPBE	.	a	(s)	C	(s)	.	a	.	a
PSME/OSCH	S	a	.	C	(S)	.	.	a	.
PSME/SYAL, SYAL	(S)	(s)	(s)	C	(S)	a	a	a	.
PSME/VAGL, VAGL	.	.	.	C	S	.	.	.	.
PSME/ACGL, PAMY	(s)	a	a	C	(s)	.	.	a	.
PSME/PHMA, PAMY	a	s	(s)	C	.	.	.	.	.
PSME/PHMA, PSME	.	.	a	C	.	.	a	.	.
PIEN/HYRE	.	.	(s)	(S)	a	.	C	a	(s)
PIEN/ARCO	(s)	.	(s)	(S)	(S)	.	C	a	(s)
PIEN/RIMO	.	.	(s)	.	(S)	.	C	a	(s)
PIEN/JUCO	a	.	(s)	(S)	(S)	.	C	a	(s)
PIEN/VASC	.	.	(s)	.	(S)	.	C	c	(S)
PIEN/LIBO	.	.	.	(S)	S	.	C	.	a
PIEN/GATR	.	.	.	s	s	(S)	C	c	.
PIEN/CADI	a	.	.	.	.	(S)	C	c	.
PIEN/CALE	.	.	a	.	s	.	C	c	s
PIEN/EQAR	a	.	.	.	s	(S)	C	c	.

(con.)

APPENDIX B (con.)

HABITAT TYPE, PHASE	POTR	JUSC	PIFL	PSME	PICO	PIPU	PIEN	ABLA	PIAL
ABLA/CACA, CACA	.	.	a	.	S	.	S	C	a
ABLA/ACRU	a	.	.	(S)	s	(s)	S	C	a
ABLA/PHMA	(s)	.	a	S	a	.	s	C	.
ABLA/ACGL, PAMY	a	.	a	S	(s)	.	S	C	a
ABLA/LIBO, VASC	.	.	a	(s)	S	.	S	C	a
ABLA/LIBO, LIBO	(s)	a	a	(S)	S	.	S	C	a
ABLA/VAGL, VASC	.	.	a	a	S	.	S	C	s
ABLA/VAGL, PAMY	.	.	a	s	S	.	S	C	(s)
ABLA/VAGL, VAGL	.	.	.	S	S	.	S	C	(s)
ABLA/VASC, CARU	a	.	.	s	S	.	a	C	a
ABLA/VASC, PIAL	.	.	.	a	S	.	S	C	C
ABLA/VASC, VASC	.	.	a	(s)	S	.	S	C	s
ABLA/ARLA	(S)	.	a	(S)	(S)	.	S	C	(S)
ABLA/SYAL	(S)	a	a	S	S	.	S	C	.
ABLA/THOC	(S)	.	a	S	S	.	S	C	s
ABLA/OSCH, PAMY	(S)	a	(s)	S	(S)	.	s	C	(s)
ABLA/OSCH, OSCH	(S)	.	.	S	(S)	.	s	C	.
ABLA/SPBE	.	.	.	S	S	.	s	C	.
ABLA/CARU, PAMY	(S)	.	a	S	(S)	.	(s)	C	.
ABLA/CARU, CARU	(S)	.	a	(S)	S	.	(s)	C	.
ABLA/BERE	(S)	.	s	S	(S)	.	(S)	C	.
ABLA/JUCO	a	a	s	(S)	S	.	(S)	C	s
ABLA/RIMO, RIMO	.	.	a	a	(s)	.	S	C	s
ABLA/RIMO, PIAL	.	.	.	.	.	.	c	C	C
ABLA/PERA	.	.	(s)	(S)	S	.	S	C	(s)
ABLA/ARCO, PIEN	.	.	a	(s)	S	.	S	C	(s)
ABLA/ARCO, SHCA	s	.	s	s	S	.	s	C	s
ABLA/ARCO, ASMI	.	.	s	(S)	S	.	s	C	.
ABLA/ARCO, ARCO	(S)	.	s	s	S	.	s	C	(s)
ABLA/CARO	(s)	.	(s)	.	S	.	a	C	.
PIAL/VASC	.	.	.	.	C	.	c	c	C
PIAL/CAGE	.	.	.	a	(C)	.	.	a	C
PIAL/JUCO, SHCA	a	.	s	a	C	.	a	a	C
PIAL/JUCO, JUCO	s	.	s	a	C	.	a	a	C
PIAL/CARO, PICO	a	.	s	.	C	.	.	c	C
PIAL/CARO, CARO	.	.	.	.	.	.	c	a	C
PIAL/FEID	a	.	.	.	a	.	a	.	C

APPENDIX C-1

APPENDIX C-1

Constancy* and average canopy coverage (percent) of important plants in eastern Idaho-western Wyoming habitat types and phases.

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PINUS FLEXILIS HEKI n=22	FEID n= 3	CELE n= 3	JUCO n= 6	PSEUDOTSUGA MENZIESII SYOR n=15	ARCO ARCO n=21	ARCO ASMI n= 3	CELE n= 8	JUCO n=21	BERE SYOR n= 3	BERE JUCO n= 6	BERE BERE n=24
	TREES												
002	Abies lasiocarpa	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (2)	- (0)	- (0)	1 (2)
007	Picea engelmannii	+ (0)	- (0)	- (0)	3 (0)	- (0)	1 (0)	- (0)	- (0)	2 (10)	- (0)	- (0)	- (0)
008	Picea glauca	- (0)	- (0)	- (0)	2 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
022	Picea pungens	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
009	Pinus albicaulis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
010	Pinus contorta	1 (9)	- (0)	- (0)	7 (35)	- (0)	1 (7)	3 (0)	- (0)	2 (18)	- (0)	10 (13)	1 (15)
011	Pinus flexilis	10 ([illegible])	10 (46)	10 (15)	10 (46)	5 (13)	5 (7)	10 (6)	3 (8)	7 (8)	3 (0)	7 (21)	2 (5)
014	Populus tremuloides	+ ([illegible])	- (0)	- (0)	3 (2)	2 (1)	1 (2)	3 (3)	- (0)	2 (2)	- (0)	5 (15)	1 (37)
016	Pseudotsuga menziesii	8 (35)	3 (15)	10 (15)	5 ([illegible])	10 (52)	10 ([illegible])	10 (54)	10 (19)	10 (43)	10 (54)	10 (38)	10 (74)
	SHRUBS AND SUBSHRUBS												
102	Acer glabrum	- (0)	- (0)	- (0)	- (0)	3 (3)	2 (2)	3 (3)	1 (3)	3 (3)	- (0)	3 (5)	5 (2)
167	Acer grandidentatum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	- (0)	2 (1)
104	Alnus sinuata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
105	Amelanchier alnifolia	- (0)	- (0)	7 (2)	- (0)	4 (2)	1 (1)	- (0)	5 (12)	2 (1)	10 (3)	5 (1)	8 (8)
201	Arctostaphylos uva-ursi	- (0)	- (0)	- (0)	- (0)	- (0)	1 (0)	- (0)	- (0)	1 (3)	- (0)	3 (0)	- (0)
150	Artemisia tridentata	5 (7)	10 (1)	10 (14)	- (0)	4 (4)	1 (0)	3 (0)	6 (4)	2 (0)	7 (20)	- (0)	+ (1)
203	Berberis repens	+ (1)	- (0)	10 (5)	- (0)	6 (1)	4 (1)	- (0)	10 (8)	3 (1)	10 (11)	10 (16)	10 (15)
107	Ceanothus velutinus	- (0)	- (0)	7 (1)	- (0)	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	- (0)	1 (19)
173	Cercocarpus ledifolius	- (0)	- (0)	10 (15)	- (0)	- (0)	- (0)	- (0)	10 (44)	- (0)	3 (3)	- (0)	1 (1)
204	Clematis columbiana	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	1 (2)	- (0)	- (0)	1 (1)
112	Juniperus communis	5 (1)	7 (3)	- (0)	10 (13)	3 (2)	5 (2)	7 (1)	- (0)	10 (30)	- (0)	10 (9)	2 (0)
153	Juniperus horizontalis	- (0)	- (0)	- (0)	2 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
113	Ledum glandulosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
206	Linnaea borealis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
115	Lonicera utahensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	+ (1)
116	Menziesia ferruginea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
118	Pachistima myrsinites	+ (1)	- (0)	7 (2)	- (0)	1 ([illegible])	2 (1)	3 (1)	8 (4)	1 (3)	7 (31)	3 (2)	9 (17)
122	Physocarpus malvaceus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)
169	Physocarpus monogynus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
124	Prunus virginiana	+ (0)	- (0)	- (0)	- (0)	3 (5)	1 (0)	- (0)	6 (7)	1 (15)	3 (15)	3 (1)	6 (15)
125	Purshia tridentata	1 (6)	- (0)	3 (3)	- (0)	1 (3)	+ (1)	- (0)	- (0)	- (0)	3 (1)	2 (1)	- (0)
128	Ribes cereum	5 ([illegible])	- (0)	- (0)	2 (1)	4 (1)	3 (1)	3 (1)	3 (1)	2 (4)	- (0)	- (0)	- (0)
158	Ribes hudsonianum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
130	Ribes lacustre	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
159	Ribes montigenum	+ (0)	- (0)	- (0)	- (0)	1 ([illegible])	1 ([illegible])	- (0)	- (0)	1 (2)	- (0)	- (0)	+ (0)
131	Ribes viscosissimum	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (2)	3 (1)	- (0)	1 (1)	- (0)	- (0)	2 (0)
132	Rosa acicularis	+ (0)	- (0)	- (0)	- (0)	1 ([illegible])	1 (2)	- (0)	- (0)	1 (1)	- (0)	3 (0)	+ (1)
161	Rosa nutkana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)
134	Rosa woodsii	3 (1)	- (0)	- (0)	3 (6)	3 (5)	4 (3)	3 (1)	4 (3)	5 (3)	- (0)	3 (8)	5 (2)
136	Rubus parviflorus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)
137	Salix scouleriana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	0 (0)	1 (3)
139	Shepherdia canadensis	+ ([illegible])	- (0)	3 (3)	3 (8)	1 (1)	5 (11)	3 (1)	- (0)	4 (3)	3 (1)	8 (10)	2 ([illegible])
140	Sorbus scopulina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (2)
142	Spiraea betulifolia	- (0)	- (0)	- (0)	- (0)	1 (1)	[illegible]	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
143	Symphoricarpos albus	- (0)	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	3 (3)	1 (1)	- (0)	- (0)	+ (3)
163	Symphoricarpos oreophilus	5 (2)	- (0)	10 (3)	3 (1)	9 (17)	8 (9)	7 (1)	8 ([illegible])	7 (4)	10 (46)	7 (15)	9 (8)
145	Vaccinium caespitosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)-	- (0)	- (0)	- (0)
146	Vaccinium globulare	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
148	Vaccinium scoparium	- (0)	- (0)	- (0)	(0)	- (0)	+ (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
	FERNS AND ALLIES												
154	Equisetum arvensis	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
	GRAMINOIDS												
301	Agropyron spicatum	7 (6)	7 (8)	7 (3)	3 ([illegible])	9 (6)	2 (1)	- (0)	8 (28)	[illegible]	3 (3)	- (0)	1 (1)
338	Bromus ciliatus	1 (6)	3 ([illegible])	- (0)	- (0)	1 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	5 (2)	1 (1)
304	Bromus vulgaris	- (0)	- (0)	- (0)	2 (1)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
305	Calamagrostis canadensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
307	Calamagrostis rubescens	- (0)	- (0)	- (0)	- (0)	- (0)	1 ([illegible])	- (0)	- (0)	1 (8)	3 (1)	3 (1)	3 (2)
334	Carex disperma	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
309	Carex geyeri	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	3 (4)
311	Carex rossii	9 ([illegible])	3 (5)	3 (1)	10 (3)	7 ([illegible])	3 (1)	7 (1)	3 (1)	6 (1)	3 (1)	8 (0)	4 (1)
316	Elymus glaucus	+ (3)	- (0)	- (0)	- (0)	[illegible]	1 (3)	- (0)	- (0)	1 (1)	- (0)	- (0)	2 (5)
317	Festuca idahoensis	5 (1)	10 (15)	3 (1)	- (0)	6 (5)	5 (4)	- (0)	1 (3)	1 (1)	3 (1)	8 (1)	1 (1)
318	Hesperochloa kingii	10 (17)	10 (5)	10 (2)	5 (6)	4 (2)	5 (1)	3 (1)	6 (2)	6 ([illegible])	- (0)	- (0)	[illegible] (1)
321	Juncus drummondii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
323	Koeleria cristata	2 (1)	3 ([illegible])	7 (1)	3 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
325	Luzula hitchcockii	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
326	Luzula parviflora	- (0)	- (0)	- (0)	[illegible]	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
329	Melica bulbosa	- (0)	- (0)	7 (1)	- (0)	1 (1)	- (0)	- (0)	1 (1)	1 (1)	- (0)	- (0)	+ (1)
339	Oryzopsis asperifolia	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)
341	Poa nervosa	1 (3)	- (0)	7 (2)	3 (1)	4 (6)	5 (10)	- (0)	1 (3)	3 (4)	- (0)	8 (6)	5 (2)
366	Stipa occidentalis	- (0)	1 (1)	- (0)	- (0)	2 (1)	+ (15)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (5)

*Code to constancy values: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

(con.)

APPENDIX C-1

APPENDIX C-1 (con.)

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PINUS FLEXILIS HEKI n=22	FEID n= 3	CELF n= 3	JUCO n= 6	PSEUDOTSUGA MENZIESII SYOR n=15	ARCO ARCO n=21	ARCO ASMI n= 3	CELE n= 8	JUCO n=21	BERE SYOR n= 3	BERE JUCO n= 6	BERE BERE n=24
	FORBS												
401	Achillea millefolium	3 (1)	7 (2)	7 (2)	7 (1)	5 (3)	2 (1)	- (0)	10 (1)	2 (1)	3 (1)	[illegible] (0)	[illegible]
402	Actaea rubra	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
565	Aconitum columbianum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
404	Allium cernuum	4 (1)	- (0)	- (0)	2 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)
409	Antennaria anaphaloides	- (0)	- (0)	- (0)	- (0)	1 (3)	1 (0)	- (0)	- (0)	- (0)	- (0)	3 (1)	- (0)
414	Antennaria microphylla	6 (1)	7 (2)	- (0)	7 (1)	5 (1)	4 (3)	7 (43)	- (0)	4 (0)	3 (1)	5 (2)	1 (1)
573	Antennaria parvifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0	(0)	- (0)
413	Antennaria racemosa	- (0)	- (0)	- (0)	2 (1)	- (0)	1 (0)	- (0)	0 (0)	1 (15)	- (0)	- (0)	- (0)
754	Aquilegia coerulea	- (0)	- (0)	- (0)	- (0)	1 (2)	3 (2)	- (0)	- (0)	- (0)	- (0)	3 (1)	- (1)
420	Arenaria macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	- (0)	- (0)	- ( )	+ (1)
421	Arnica cordifolia	+ (1)	- (0)	- (0)	8 (2)	6 (1)	10 (23)	3 (3)	4 (14)	7 (6)	- (0)	7 (17)	8 (18)
422	Arnica latifolia	- (0)	- (0)	- (0)	- ( )	- (0)	- (0)	- (0)	- ( )	- ( )	- (0)	- (0)	- (0)
426	Aster conspicuus	- (0)	- (0)	- (0)	2 (1)	1 (3)	1 (20)	- (0)	- (0)	[illegible] (3[illegible]	- (0)	- (0)	- ( )
582	Aster engelmannii	- (0)	- (0)	3 (3)	- (0)	1 (1)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	3 (1)
822	Aster glaucodes	1 (1)	- (0)	- (0)	2 (1)	1 (2)	2 (2)	- (0)	3 (1)	1 (8)	- ( )	3 (3)	2 (1)
430	Astragalus miser	6 (13)	3 (3)	- (0)	7 (5)	4 (11)	4 (27)	10 (34)	- (0)	6 (18)	- (0)	3 (17)	- (0)
817	Balsamorhiza macrophylla	- (0)	- (0)	7 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)
431	Balsamothiza sagittata	5 (6)	7 (9)	10 (6)	2 (3)	4 (7)	1 (0)	- (0)	6 (5)	1 (1)	10 (1)	3 (1)	3 (1)
843	Balsamorhiza incana	+ (3)	- (0)	- (0)	2 (3)	- (0)	+ (1)	- (0)	- (0)	1 (0)	- (0)	3 (1)	- (0)
769	Caltha leptosepala	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
436	Campanula rotundifolia	5 (0)	7 (1)	- (0)	5 (0)	2 (1)	2 (0)	3 (1)	1 (3)	3 (1)	- (0)	5 (0)	- (0)
438	Castilleja miniata	- (0)	- (0)	- (0)	2 (1)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
594	Castilleja rhexifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
442	Chimaphila umbellata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)
599	Clematis pseudoalpina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
600	Clematis tenuiloba	- (0)	- (0)	- (0)	2 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0	- ( )
602	Crepis acuminata	6 (2)	10 (1)	3 (1)	- (0)	2 (1)	+ (1)	3 (1)	8 (3)	2 (1)	3 (1)	5 (1)	1 (2)
847	Cymopteris hendersonii	1 (2)	- (0)	- (0)	2 (1)	1 (1)	3 (3)	3 (1)	- (0)	2 (1)	- (0)	2 (1)	- (0)
455	Disporum trachycarpum	- (0)	- (0)	- (0)	- (0)	1 (1)	+ (1)	- (0)	1 (1)	1 (3)	- (0)	- (0)	3 (1)
459	Epilobium angustifolium	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	3 (1)	1 (0)
465	Fragaria vesca	+ (1)	- (0)	- (0)	2 (1)	1 (1)	1 (2)	3 (1)	1 (3)	1 (1)	3 (3)	- (0)	5 (3)
466	Fragaria virginiana	+ (1)	3 (1)	- (0)	2 (1)	1 (15)	1 (8)	- (0)	- (0)	1 (3)	- (0)	3 (1)	1 (2)
616	Frasera speciosa	1 (1)	- (0)	- (0)	2 (1)	1 (1)	4 (1)	- (0)	- (0)	1 (1)	- (0)	3 (8)	3 (0)
471	Galium triflorum	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
620	Geranium richardsonii	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (15)
473	Geranium viscosissimum	- (0)	- (0)	- (0)	- (0)	1 (3)	+ (1)	- (0)	- (0)	1 (1)	7 (1)	- (0)	1 (1)
474	Geum triflorum	+ (3)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
476	Goodyera oblongifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (0)
481	Heracleum lanatum	- ( )	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
484	Hieracium albiflorum	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (0)
486	Heracium gracile	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
756	Ligusticum filicinum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
639	Linum perenne	+ (1)	3 (3)	3 (3)	2 (1)	1 (1)	- (0)	- (0)	3 (8)	- (0)	- (0)	- (0)	- (0)
641	Lupinus argenteus	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
649	Mitella pentandra	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
502	Mitella stauropetala	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	5 (1)
505	Osmorhiza chilensis	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (2)	- (0)	1 (3)	1 (1)	3 (1)	- (0)	6 (2)
653	Osmorhiza depauperata	- (0)	- (0)	- (0)	2 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	3 (1)	2 (1)
507	Pedicularis bracteosa	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
509	Pedicularis racemosa	- (0)	- (0)	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (3)
513	Penstemon procerus	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
669	Potentilla diversifolia	1 (0)	- (0)	- (0)	- (0)	- (0)	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
521	Potentilla flabellifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (1)	- (0)
670	Potentilla gracilis	- (0)	- (0)	- (0)	2 (1)	1 (1)	1 (2)	- (0)	- (0)	1 (1)	- (0)	- (0)	+ (1)
702	Potentilla ovina	1 (1)	7 (2)	- (0)	3 (1)	- (0)	+ (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
526	Pyrola asarifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)
529	Pyrola secunda	- (0)	- (0)	- (0)	2 (1)	- (0)	1 (2)	3 (1)	- (0)	2 (1)	- (0)	5 (1)	2 (2)
676	Saxifraga arguta	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
840	Senecio lugens	- (0)	- (0)	- (0)	2 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	- (0)
681	Senecio streptanthifolius	+ (3)	3 (3)	- (0)	5 (1)	4 (1)	2 (1)	- (0)	4 (2)	2 (1)	3 (1)	3 (1)	- (0)
539	Senecio triangularis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
541	Silene menziesii	- (0)	- (0)	- (0)	- (0)	2 (1)	+ (1)	- (0)	4 (1)	- (0)	- (0)	- ( )	4 (1)
542	Smilacina racemosa	- (0)	- (0)	- (0)	- (0)	2 (1)	- (0)	- (0)	8 (1)	- (0)	- (0)	- (0)	6 (2)
543	Smilacina stellata	+ (1)	- (0)	- (0)	- (0)	1 (1)	+ (3)	- (0)	- (0)	- (0)	3 (1)	- (0)	- (0)
684	Solidago multiradiata	3 (1)	- (0)	- (0)	3 (2)	1 (2)	2 (2)	- (0)	1 (3)	2 (1)	- (0)	3 ( )	- (0)
546	Streptopus amplexifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
714	Thalictrum fendleri	- (0)	- (0)	3 (3)	- (0)	1 (1)	- (0)	- (0)	3 (0)	- (0)	3 (1)	- (0)	4 (9)
547	Thalictrum occidentale	- (0)	- (0)	- (0)	2 (0)	1 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)
690	Trollius laxus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
550	Valeriana dioica & occidentalis	- (0)	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	- (0)
554	Viola adunca	+ (1)	- (0)	- (0)	2 (1)	1 (1)	+ (0)	- (0)	1 (1)	- (0)	3 (1)	- (0)	4 ( )
555	Viola canadensis	- (0)	- (0)	- (0)	- (0)	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
693	Viola nuttallii	- (0)	- (0)	- (0)	- (0)	1 (1)	+ (1)	- (0)	1 (1)	- (0)	3 (1)	- (0)	+ (1)
557	Viola orbiculata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
694	Viola purpurea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	7 (1)	- (0)	1 ( )
558	Xerophyllum tenax	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)

APPENDIX C-1

Constancy* and average canopy coverage (percent) of important plants in eastern Idaho-western Wyoming habitat types and phases

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PSEUDOTSUGA MENZIESII CARU PAMY n=13	CARU CARU n=27	SPBE CARU n=10	SPBE SPBE n= 9	OSCH n=24	SYAL n=18	VAGL n= 3	ACGL PAMY n=25	PHMA PAMY n=17	PHMA PSME n= 5
	TREES										
002	Abies lasiocarpa	2 (1)	1 (1)	- (0)	- (0)	2 (1)	1 (3)	- (0)	2 (2)	1 (0)	- (0)
007	Picea engelmannii	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	6 (1)
008	Picea glauca	- (0)	- (0)	- (0)	1 (3)	- (0)	1 (2)	- (0)	- (0)	- (0)	- (0)
022	Picea pungens	- (0)	- (0)	- (0)	- (0)	- (0)	1 (2)	- (0)	- (0)	- (0)	- (0)
009	Pinus albicaulis	- (0)	- (0)	- (0)	1 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
010	Pinus contorta	2 (20)	4 (16)	3 (23)	2 (9)	1 (20)	2 (8)	7 (26)	2 (21)	- (0)	- (0)
011	Pinus flexilis	1 (1)	1 (8)	1 (1)	3 (11)	- (0)	2 (9)	- (0)	2 (1)	2 (5)	4 (2)
014	Populus tremuloides	4 (14)	+ (63)	2 (2)	- (0)	5 (24)	2 (25)	- (0)	3 (15)	1 (3)	- (0)
016	Pseudotsuga menziesii	10 (58)	10 (55)	10 (66)	10 (59)	10 (68)	10 (55)	10 (38)	10 (62)	10 (59)	10 (62)
	SHRUBS AND SUBSHRUBS										
102	Acer glabrum	5 (3)	1 (0)	4 (2)	3 (3)	3 (2)	3 (1)	- (0)	8 (27)	6 (11)	2 (1)
167	Acer grandidentatum	- (0)	+ (3)	1 (1)	- (0)	1 (34)	1 (19)	- (0)	2 (14)	1 (8)	- (0)
104	Alnus sinuata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
105	Amelanchier alnifolia	8 (5)	3 (4)	4 (8)	4 (9)	8 (11)	6 (8)	7 (15)	8 (13)	7 (7)	2 (1)
201	Arctostaphylos uva-ursi	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)
150	Artemisia tridentata	1 (0)	2 (3)	1 (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
203	Berberis repens	9 (9)	7 (2)	8 (5)	8 (8)	8 (5)	8 (3)	- (0)	9 (6)	8 (7)	2 (1)
107	Ceanothus velutinus	2 (1)	- (0)	1 (1)	- (0)	- (0)	1 (1)	- (0)	1 (2)	- (0)	- (0)
173	Cercocarpus ledifolius	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	1 (19)	- (0)
204	Clematis columbiana	- (0)	1 (5)	1 (1)	1 (1)	+ (1)	3 (1)	3 (15)	4 (4)	2 (5)	4 (0)
112	Juniperus communis	1 (1)	1 (8)	1 (0)	4 (2)	- (0)	4 (3)	- (0)	1 (1)	1 (2)	6 (1)
153	Juniperus horizontalis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
113	Ledum glandulosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
206	Linnaea borealis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)
115	Lonicera utahensis	1 (3)	+ (1)	5 (1)	1 (1)	- (0)	2 (1)	10 (6)	3 (10)	3 (4)	- (0)
116	Menziesia ferruginea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
118	Pachistima myrsinites	10 (25)	3 (1)	4 (5)	6 (26)	5 (7)	3 (4)	3 (3)	7 (9)	10 (10)	- (0)
122	Physocarpus malvaceus	1 (1)	- (0)	1 (1)	1 (0)	+ (3)	1 (1)	- (0)	1 (2)	10 (61)	10 (53)
169	Physocarpus monogynus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
124	Prunus virginiana	7 (8)	3 (6)	4 (6)	3 (15)	5 (13)	6 (13)	- (0)	7 (8)	5 (9)	- (0)
125	Purshia tridentata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)
128	Ribes cereum	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
158	Ribes hudsonianum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
130	Ribes lacustre	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	+ (1)	- (0)	2 (3)
159	Ribes montigenum	- (0)	+ (1)	1 (0)	1 (1)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)
131	Ribes viscosissimum	3 (0)	1 (2)	2 (1)	1 (1)	1 (2)	1 (1)	3 (3)	4 (1)	1 (3)	- (0)
132	Rosa acicularis	- (0)	+ (1)	- (0)	- (0)	- (0)	2 (11)	- (0)	+ (3)	- (0)	- (0)
161	Rosa nutkana	2 (1)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)
134	Rosa woodsii	2 (1)	1 (1)	- (0)	- (0)	3 (4)	1 (2)	- (0)	2 (2)	1 (3)	- (0)
136	Rubus parviflorus	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (2)	1 (15)	- (0)
137	Salix scouleriana	2 (9)	+ (3)	1 (3)	- (0)	1 (26)	- (0)	7 (15)	2 (3)	2 (2)	- (0)
139	Shepherdia canadensis	2 (1)	1 (2)	1 (15)	4 (0)	- (0)	2 (6)	3 (1)	1 (4)	1 (1)	1 (1)
140	Sorbus scopulina	4 (4)	+ (1)	4 (1)	1 (1)	1 (2)	1 (3)	10 (2)	5 (10)	1 (0)	- (0)
142	Spiraea betulifolia	1 (3)	2 (2)	10 (26)	10 (23)	1 (26)	8 (28)	10 (30)	4 (31)	4 (13)	10 (2)
143	Symphoricarpos albus	- (0)	2 (3)	3 (3)	3 (2)	1 (2)	10 (21)	- (0)	3 (17)	4 (6)	4 (2)
163	Symphoricarpos oreophilus	10 (9)	6 (9)	4 (5)	6 (4)	8 (6)	1 (3)	- (0)	6 (7)	4 (5)	- (0)
145	Vaccinium caespitosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
146	Vaccinium globulare	- (0)	+ (1)	1 (3)	- (0)	- (0)	- (0)	10 (54)	2 (38)	- (0)	- (0)
148	Vaccinium scoparium	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	7 (8)	- (0)	- (0)	- (0)
	FERNS AND ALLIES										
254	Equisetum arvensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
	GRAMINOIDS										
301	Agropyron spicatum	1 (15)	- (0)	1 (1)	3 (6)	- (0)	3 (5)	- (0)	1 (1)	2 (2)	- (0)
338	Bromus ciliatus	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)
304	Bromus vulgaris	- (0)	- (0)	- (0)	- (0)	+ (1)	1 (1)	- (0)	- (0)	1 (1)	- (0)
305	Calamagrostis canadensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
307	Calamagrostis rubescens	10 (39)	10 (52)	10 (43)	3 (3)	8 (8)	6 (32)	10 (11)	6 (18)	7 (5)	2 (15)
339	Carex disperma	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
309	Carex geyeri	3 (5)	4 (14)	5 (38)	3 (18)	3 (11)	1 (2)	7 (9)	4 (6)	2 (5)	- (0)
311	Carex rossii	2 (1)	2 (1)	4 (1)	1 (3)	4 (1)	3 (2)	7 (2)	2 (1)	5 (1)	2 (1)
316	Elymus glaucus	2 (1)	2 (7)	3 (2)	3 (2)	3 (5)	1 (1)	3 (3)	2 (5)	4 (1)	- (0)
317	Festuca idahoensis	1 (1)	1 (1)	- (0)	- (0)	+ (1)	3 (5)	- (0)	- (0)	- (0)	2 (1)
348	Hesperochloa kingii	- (0)	- (0)	- (0)	2 (1)	- (0)	1 (3)	- (0)	1 (2)	1 (1)	8 (2)
321	Juncus drummondii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
323	Koeleria cristata	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
325	Luzula hitchcockii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
326	Luzula parviflora	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
349	Melica bulbosa	- (0)	1 (1)	- (0)	- (0)	+ (1)	- (0)	- (0)	+ (1)	- (0)	- (0)
329	Oryzopis asperifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)
331	Poa nervosa	2 (2)	4 (1)	4 (1)	7 (2)	3 (5)	3 (5)	- (0)	+ (3)	4 (1)	2 (15)
360	Stipa occidentalis	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)

*Code to constancy values: + = 0- 5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

(con.)

APPENDIX C-1

APPENDIX C-1 (con.)

ADP NO.	SERIES	PSEUDOTSUGA MENZIESII									
	HABITAT TYPE	CARU	CARU	SPBE	SPBE	OSCH	SYAL	VAGL	ACGL	PHMA	PHMA
	PHASE	PAMY	CARU	CARU	SPBE				PAMY	PAMY	PSME
	NUMBER OF STANDS	n=13	n=27	n=10	n= 9	n=24	n=18	n= 3	n=25	n=17	n= 5
	FORBS										
401	Achillea millefolium	2 (1)	8 (1)	3 (1)	7 (1)	5 (1)	6 (1)	- (0)	1 (2)	4 (1)	4 (0)
402	Actaea rubra	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (1)	1 (1)	- (0)
465	Aconitum columbianum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
404	Allium cernuum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
409	Antennaria anaphaloides	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
414	Antennaria microphylla	2 (1)	2 (1)	1 (1)	- (0)	+ (1)	3 (1)	- (0)	- (0)	1 (1)	4 (1)
573	Antennaria parvifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)
413	Antennaria racemosa	- (0)	1 (2)	1 (1)	2 (3)	- (0)	1 (1)	- (0)	1 (1)	- (0)	- (0)
754	Aquilegia coerulea	1 (1)	+ (1)	- (0)	- (0)	+ (1)	- (0)	- (0)	+ (1)	- (0)	- (0)
420	Arenaria macrophylla	2 (1)	- (0)	- (0)	- (0)	- (0)	1 (0)	- (0)	- (0)	- (0)	- (0)
421	Arnica cordifolia	9 (9)	9 (13)	9 (11)	8 (15)	5 (24)	4 (9)	7 (9)	7 (12)	6 (8)	10 (5)
422	Arnica latifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (3)	- (0)	- (0)
426	Aster conspicuus	- (0)	+ (37)	- (0)	2 (9)	- (0)	3 (9)	- (0)	2 (9)	1 (1)	8 (5)
582	Aster engelmannii	2 (5)	3 (3)	6 (2)	3 (2)	2 (1)	2 (1)	7 (1)	4 (6)	2 (1)	- (0)
822	Aster glaucodes	- (0)	+ (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
430	Astragalus miser	- (0)	5 (11)	2 (8)	6 (7)	1 (2)	4 (21)	- (0)	1 (9)	1 (26)	8 (5)
817	Balsamorhiza macrophylla	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
431	Balsamorhiza sagittata	1 (3)	1 (1)	3 (1)	3 (10)	1 (3)	3 (14)	- (0)	1 (8)	1 (8)	- (0)
843	Balsamorhiza incana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
769	Caltha leptosepala	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
436	Campanula rotundifolia	- (0)	1 (1)	1 (1)	2 (2)	+ (1)	1 (2)	- (0)	1 (1)	2 (1)	- (0)
438	Castilleja miniata	2 (0)	+ (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)
594	Castilleja rhexifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
442	Chimaphila umbellata	2 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	3 (3)	2 (1)	- (0)	- (0)
599	Clematis pseudoalpina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	4 (1)
600	Clematis tenuiloba	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
602	Crepis acuminata	1 (3)	1 (1)	- (0)	2 (8)	- (0)	4 (1)	- (0)	- (0)	- (0)	- (0)
847	Cymopteris hendersonii	- (0)	1 (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
455	Disporum trachycarpum	2 (0)	1 (1)	2 (2)	4 (2)	5 (1)	3 (4)	3 (15)	6 (1)	5 (2)	4 (11)
459	Epilobium angustifolium	1 (1)	3 (3)	- (0)	1 (1)	1 (1)	2 (1)	- (0)	2 (2)	2 (1)	2 (1)
465	Fragaria vesca	5 (3)	6 (3)	4 (5)	3 (1)	5 (2)	3 (7)	7 (1)	4 (5)	6 (3)	2 (1)
466	Fragaria virginiana	2 (1)	2 (3)	- (0)	3 (6)	1 (2)	4 (3)	- (0)	2 (1)	2 (2)	6 (1)
616	Frasera speciosa	- (0)	1 (1)	2 (1)	2 (1)	- (0)	2 (1)	- (0)	1 (1)	1 (2)	2 (1)
471	Galium triflorum	- (0)	+ (1)	1 (3)	- (0)	1 (2)	- (0)	- (0)	4 (1)	3 (1)	- (0)
620	Geranium richardsonii	1 (1)	2 (2)	1 (3)	1 (1)	- (0)	1 (15)	- (0)	2 (1)	1 (1)	- (0)
473	Geranium viscosissimum	2 (3)	6 (3)	3 (2)	2 (1)	3 (1)	3 (1)	- (0)	2 (1)	2 (1)	2 (1)
474	Geum triflorum	1 (3)	1 (1)	- (0)	1 (1)	+ (1)	2 (1)	- (0)	- (0)	1 (1)	- (0)
476	Goodyera oblongifolia	2 (1)	1 (1)	3 (1)	1 (1)	2 (1)	1 (1)	7 (1)	2 (2)	4 (1)	- (0)
481	Heracleum lanatum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
484	Hieracium albiflorum	2 (0)	1 (1)	2 (3)	- (0)	2 (1)	1 (0)	10 (2)	1 (2)	1 (2)	- (0)
486	Hieracium gracile	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)
756	Ligusticum filicinum	- (0)	+ (1)	1 (1)	- (0)	+ (1)	- (0)	- (0)	+ (1)	- (0)	- (0)
639	Linum perenne	1 (1)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
641	Lupinus argenteus	1 (1)	3 (3)	- (0)	- (0)	1 (1)	2 (1)	- (0)	- (0)	- (0)	- (0)
649	Mitella pentandra	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
502	Mitella stauropetala	5 (1)	1 (2)	- (0)	- (0)	5 (2)	- (0)	- (0)	4 (5)	4 (4)	- (0)
505	Osmorhiza chilensis	6 (1)	4 (1)	7 (4)	4 (2)	8 (22)	2 (1)	7 (3)	5 (5)	4 (1)	- (0)
653	Osmorhiza depauperata	- (0)	2 (1)	- (0)	1 (1)	3 (31)	2 (1)	- (0)	4 (19)	1 (3)	- (0)
507	Pedicularis bracteosa	1 (1)	1 (1)	2 (2)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
509	Pedicularis racemosa	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	3 (1)	1 (11)	1 (1)	- (0)
513	Penstemon procerus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
669	Potentilla diversifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
521	Potentilla flabellifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
670	Potentilla gracilis	- (0)	1 (2)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
702	Potentilla ovina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
526	Pyrola asarifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
529	Pyrola secunda	3 (0)	1 (1)	2 (2)	2 (2)	2 (1)	- (0)	7 (2)	4 (2)	1 (3)	2 (1)
676	Saxifraga arguta	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
840	Senecio lugens	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
681	Senecio streptanthifolius	2 (2)	2 (2)	1 (1)	2 (3)	+ (1)	2 (2)	- (0)	+ (1)	2 (1)	- (0)
539	Senecio triangularis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
541	Silene menziesii	2 (1)	3 (1)	- (0)	- (0)	5 (1)	1 (1)	- (0)	3 (1)	2 (1)	- (0)
542	Smilacina racemosa	6 (3)	3 (1)	4 (5)	3 (1)	6 (2)	6 (1)	3 (1)	7 (1)	8 (3)	4 (1)
543	Smilacina stellata	- (0)	1 (1)	- (0)	- (0)	- (0)	1 (1)	- (0)	+ (1)	1 (1)	- (0)
684	Solidago multiradiata	- (0)	1 (1)	1 (1)	3 (1)	- (0)	2 (5)	- (0)	- (0)	1 (2)	2 (1)
546	Streptopus amplexifolius	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)
714	Thalictrum fendleri	2 (1)	2 (4)	1 (15)	2 (8)	5 (4)	3 (11)	- (0)	5 (6)	4 (7)	- (0)
547	Thalictrum occidentale	5 (3)	2 (2)	5 (12)	2 (20)	2 (14)	2 (10)	7 (8)	1 (26)	1 (2)	2 (1)
690	Trollius laxus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
550	Valeriana dioica & occidentalis	- (0)	3 (3)	2 (1)	1 (3)	3 (2)	1 (1)	- (0)	1 (1)	- (0)	4 (3)
554	Viola adunca	5 (1)	2 (1)	- (0)	2 (1)	3 (1)	1 (1)	- (0)	4 (1)	5 (1)	2 (1)
555	Viola canadensis	- (0)	+ (3)	3 (1)	1 (1)	+ (3)	1 (1)	- (0)	2 (1)	1 (3)	- (0)
693	Viola nuttallii	1 (1)	2 (1)	- (0)	1 (1)	2 (1)	- (0)	- (0)	+ (1)	- (0)	- (0)
557	Viola orbiculata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
694	Viola purpurea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)
558	Xerophyllum tenax	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)

(con.)

APPENDIX C-1

APPENDIX C-1

Constancy* and average canopy coverage (percent) of important plants in eastern Idaho–western Wyoming habitat types and phases

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PICEA ENGELMANNII									
		EQAR	CALE	CADI	GATR	LIBO	VASC	JUCO	RIMO	ARCO	HYRE
		n=10	n=10	n= 4	n= 8	n= 8	n=13	n=21	n= 5	n=17	n=11
	TREES										
002	Abies lasiocarpa	7 (16)	7 (16)	3 (3)	6 (4)	- (0)	2 (2)	2 (2)	2 (1)	1 (15)	3 (2)
007	Picea engelmannii	8 (59)	9 (51)	3 (85)	6 (66)	9 (40)	10 (30)	10 (32)	10 (48)	9 (33)	9 (55)
008	Picea glauca	1 (37)	1 (63)	5 (74)	3 (50)	1 (85)	- (0)	- (0)	- (0)	1 (37)	1 (63)
022	Picea pungens	1 (37)	- (0)	3 (37)	1 (98)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
009	Pinus albicaulis	- (0)	2 (8)	- (0)	- (0)	1 (1)	4 (29)	1 (26)	4 (31)	3 (23)	4 (10)
010	Pinus contorta	3 (13)	2 (19)	- (0)	4 (10)	5 (27)	7 (33)	4 (13)	2 (63)	6 (15)	3 (1)
011	Pinus flexilis	- (0)	1 (15)	- (0)	- (0)	- (0)	3 (13)	8 (12)	2 (3)	4 (6)	2 (9)
014	Populus tremuloides	1 (3)	- (0)	3 (1)	- (0)	- (0)	- (0)	1 (5)	- (0)	1 (98)	- (0)
016	Pseudotsuga menziesii	- (0)	- (0)	- (0)	1 (15)	5 (38)	- (0)	7 (24)	- (0)	6 (22)	5 (27)
	SHRUBS AND SUBSHRUBS										
102	Acer glabrum	- (0)	- (0)	- (0)	3 (1)	1 (1)	- (0)	1 (3)	- (0)	1 (1)	1 (1)
167	Acer grandidentatum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
104	Alnus sinuata	- (0)	- (0)	3 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
105	Amelanchier alnifolia	2 (1)	- (0)	- (0)	4 (1)	3 (2)	- (0)	+ (1)	- (0)	- (0)	- (0)
201	Arctostaphylos uva-ursi	1 (1)	- (0)	- (0)	- (0)	6 (1)	- (0)	3 (1)	- (0)	- (0)	1 (1)
150	Artemisia tridentata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)
203	Berberis repens	1 (1)	- (0)	3 (0)	1 (1)	4 (11)	- (0)	1 (1)	- (0)	- (0)	- (0)
107	Ceanothus velutinus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
173	Cercocarpus ledifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
204	Clematis columbiana	- (0)	- (0)	- (0)	5 (1)	5 (1)	- (0)	+ (1)	- (0)	1 (1)	- (0)
112	Juniperus communis	1 (15)	1 (1)	- (0)	5 (1)	10 (4)	3 (1)	10 (16)	4 (1)	6 (1)	3 (1)
153	Juniperus horizontalis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
113	Ledum glandulosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
206	Linnaea borealis	4 (20)	- (0)	5 (26)	4 (7)	10 (25)	- (0)	- (0)	- (0)	- (0)	- (0)
115	Lonicera utahensis	3 (1)	2 (2)	- (0)	5 (1)	4 (6)	- (0)	- (0)	- (0)	- (0)	- (0)
116	Menziesia ferruginea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
118	Pachistima myrsinites	- (0)	- (0)	- (0)	3 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
122	Physocarpus malvaceus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
169	Physocarpus monogynus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
124	Prunus virginiana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
125	Purshia tridentata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
128	Ribes cereum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (0)	- (0)	- (0)	2 (1)
158	Ribes hudsonianum	1 (1)	- (0)	5 (8)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
130	Ribes lacustre	8 (4)	5 (3)	8 (5)	8 (16)	4 (2)	- (0)	1 (1)	- (0)	- (0)	1 (15)
159	Ribes montigenum	- (0)	1 (1)	- (0)	- (0)	4 (0)	2 (0)	2 (2)	10 (10)	4 (1)	4 (0)
131	Ribes viscosissimum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	1 (1)
132	Rosa acicularis	1 (3)	- (0)	- (0)	3 (15)	4 (11)	- (0)	- (0)	- (0)	- (0)	- (0)
161	Rosa nutkana	- (0)	- (0)	- (0)	1 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
134	Rosa woodsii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	5 (1)	2 (1)	2 (2)	- (0)
136	Rubus parviflorus	- (0)	- (0)	3 (1)	1 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
137	Salix scouleriana	2 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (3)
139	Shepherdia canadensis	4 (1)	- (0)	- (0)	3 (1)	6 (4)	- (0)	7 (9)	4 (1)	3 (0)	4 (1)
140	Sorbus scopulina	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
142	Spiraea betulifolia	- (0)	- (0)	- (0)	- (0)	4 (7)	- (0)	- (0)	- (0)	- (0)	- (0)
143	Symphoricarpos albus	2 (1)	- (0)	3 (1)	3 (3)	8 (15)	- (0)	- (0)	- (0)	1 (1)	- (0)
163	Symphoricarpos oreophilus	- (0)	- (0)	- (0)	- (0)	1 (0)	- (0)	4 (5)	- (0)	1 (1)	2 (1)
145	Vaccinium caespitosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
146	Vaccinium globulare	1 (1)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
148	Vaccinium scoparium	3 (1)	9 (37)	- (0)	3 (8)	1 (15)	10 (46)	- (0)	2 (1)	1 (0)	- (0)
	FERNS AND ALLIES										
254	Equisetum arvensis	10 (73)	5 (1)	10 (4)	4 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
	GRAMINOIDS										
301	Agropyron spicatum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	1 (1)	- (0)
338	Bromus ciliatus	4 (2)	2 (8)	- (0)	- (0)	- (0)	- (0)	1 (1)	2 (1)	1 (0)	- (0)
304	Bromus vulgaris	2 (2)	- (0)	- (0)	3 (1)	1 (1)	- (0)	+ (1)	- (0)	- (0)	- (0)
305	Calamagrostis canadensis	5 (5)	3 (13)	3 (1)	3 (33)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
[illegible]	Calamagrostis rubescens	1 (1)	- (0)	- (0)	4 (5)	6 (10)	- (0)	1 (0)	- (0)	- (0)	- (0)
339	Carex disperma	7 (6)	- (0)	10 (27)	1 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
309	Carex geyeri	1 (1)	- (0)	- (0)	- (0)	1 (15)	- (0)	+ (1)	- (0)	- (0)	- (0)
311	Carex rossii	- (0)	2 (1)	- (0)	- (0)	1 (3)	5 (4)	5 (1)	2 (1)	6 (1)	5 (0)
[illegible]	Elymus glaucus	3 (1)	- (0)	- (0)	3 (3)	1 (1)	- (0)	- (0)	- (0)	1 (1)	- (0)
31	Festuca idahoensis	- (0)	- (0)	- (0)	- (0)	- (0)	2 (0)	3 (1)	- (0)	5 (3)	2 (0)
348	Hesperochloa kingii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	4 (1)	- (0)	4 (1)	1 (1)
[illegible]	Juncus drummondii	- (0)	6 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
323	Koeleria cristata	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)	2 (1)	- (0)	- (0)
[illegible]	Luzula hitchcockii	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
326	Luzula parviflora	5 (1)	6 (4)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
349	Melica bulbosa	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
[illegible]	Oryzopsis asperifolia	1 (1)	- (0)	3 (1)	1 (3)	3 (9)	- (0)	- (0)	- (0)	- (0)	- (0)
331	Poa nervosa	- (0)	1 (0)	- (0)	- (0)	5 (1)	5 (4)	4 (1)	4 (8)	4 (1)	5 (1)
360	Stipa occidentalis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
334	Trisetum spicatum	- (0)	3 (1)	- (0)	- (0)	- (0)	2 (1)	2 (1)	- (0)	5 (1)	3 (1)

*Code to constancy values:

+ = 0- 5% 2 = 15-25% 4 = 35-45% 6 = 55-65% 8 = 75-85% 10 = 95-100%
1 = 5-15% 3 = 25-35% 5 = 45-55% 7 = 65-75% 9 = 85-95%

(con.)

APPENDIX C-1

APPENDIX C-1 (con.)

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PICEA ENGELMANNII									
		EQAR	CALE	CADI	GATR	LIBO	VASC	JUCO	RIMO	ARCO	HYRE
		n=10	n=10	n= 4	n= 8	n= 8	n=13	n=21	n= 5	n=17	n=11
	FORBS										
401	Achillea millefolium	1 (1)	2 (1)	3 (1)	1 (1)	1 (0)	2 (1)	3 (1)	8 (1)	6 (0)	- (0)
402	Actaea rubra	4 (5)	- (0)	8 (5)	9 (4)	4 (T)	- (0)	- (0)	- (0)	1 (T)	1 (T)
565	Aconitum columbianum	3 (7)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
404	Allium cernuum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
409	Antennaria anaphaloides	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)	4 (1)	3 (1)	- (0)
414	Antennaria microphylla	1 (1)	- (0)	3 (1)	1 (1)	- (0)	5 (1)	3 (1)	2 (1)	4 (1)	4 (0)
573	Antennaria parvifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
413	Antennaria racemosa	- (0)	- (0)	- (0)	- (0)	5 (5)	- (0)	1 (1)	2 (1)	[illegible] (5)	1 (1)
754	Aquilegia coerulea	1 (3)	3 (2)	- (0)	3 (1)	- (0)	3 (1)	4 (1)	8 (1)	6 (2)	2 (0)
420	Arenaria macrophylla	- (0)	- (0)	3 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	1 (0)	- (0)
421	Arnica cordifolia	4 (2)	5 (5)	3 (1)	4 (5)	9 (10)	8 (3)	8 (4)	10 (4)	10 (12)	6 (1)
422	Arnica latifolia	- (0)	6 (4)	- (0)	- (0)	- (0)	2 (1)	+ (1)	- (0)	- (0)	- (0)
426	Aster conspicuus	2 (1)	- (0)	3 (1)	3 (8)	6 (2)	- (0)	+ (1)	2 (1)	1 (2)	2 (2)
582	Aster engelmannii	1 (3)	- (0)	- (0)	1 (1)	1 (1)	- (0)	+ (1)	- (0)	1 (15)	- (0)
822	Aster glaucodes	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
430	Astragalus miser	1 (1)	1 (0)	- (0)	1 (1)	5 (5)	2 (3)	6 (10)	2 (15)	8 (6)	4 (0)
843	Balsamorhiza incana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	1 (1)	(0)
817	Balsamorhiza macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
431	Balsamorhiza sagittata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
769	Caltha leptosepala	- (0)	7 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
436	Campanula rotundifolia	- (0)	- (0)	- (0)	- (0)	1 (0)	- (0)	2 (0)	- (0)	2 (0)	3 (0)
438	Castilleja miniata	1 (1)	- (0)	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
594	Castilleja rhexifolia	- (0)	6 (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
442	Chimaphila umbellata	1 (1)	- (0)	- (0)	- (0)	3 (8)	- (0)	- (0)	- (0)	- (0)	- (0)
599	Clematis pseudoalpina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)
600	Clematis tenuiloba	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
602	Crepis acuminata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
847	Cymopteris hendersonii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (3)	- (0)
455	Disporum trachycarpum	2 (0)	- (0)	3 (1)	5 (1)	5 (2)	- (0)	- (0)	- (0)	1 (1)	1 (1)
459	Epilobium angustifolium	7 (3)	8 (1)	5 (1)	6 (1)	8 (1)	5 (1)	5 (1)	6 (1)	4 (1)	2 (1)
465	Fragaria vesca	4 (1)	- (0)	3 (1)	5 (1)	8 (7)	1 (1)	+ (1)	2 (3)	1 (15)	1 (1)
466	Fragaria virginiana	5 (1)	2 (1)	3 (1)	4 (13)	5 (5)	- (0)	3 (1)	4 (1)	5 (1)	1 (1)
616	Frasera speciosa	1 (1)	- (0)	- (0)	- (0)	3 (1)	- (0)	5 (2)	4 (1)	5 (1)	2 (0)
471	Galium triflorum	6 (15)	- (0)	10 (5)	5 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
620	Geranium richardsonii	6 (4)	3 (2)	10 (1)	5 (5)	4 (2)	1 (15)	- (0)	- (0)	1 (1)	- (0)
473	Geranium viscosissimum	2 (8)	- (0)	3 (1)	- (0)	1 (1)	1 (1)	+ (1)	- (0)	1 (1)	- (0)
474	Geum triflorum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	2 (1)	4 (0)	- (0)
476	Goodyera oblongifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)
481	Heracleum lanatum	2 (3)	2 (2)	3 (1)	4 (1)	- (0)	- (0)	- ([illegible])	- (0)	- (0)	- (0)
484	Hieracium albiflorum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)
486	Hieracium gracile	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)
756	Ligusticum filicinum	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
639	Linum perenne	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ([illegible])	- (0)
641	Lupinus argenteus	- (0)	- (0)	3 (1)	- (0)	- (0)	- (0)	+ (1)	- (0)	[illegible] (1)	- (0)
649	Mitella pentandra	6 (6)	6 (2)	5 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
502	Mitella stauropetala	1 (15)	1 (1)	- (0)	3 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
505	Osmorhiza chilensis	4 (2)	- (0)	3 (1)	- (0)	8 (1)	1 (3)	- (0)	- (0)	- (0)	- (0)
653	Osmorhiza depauperata	4 (1)	3 (1)	3 (1)	6 (1)	- (0)	1 (1)	1 (1)	2 (1)	2 (1)	- (0)
507	Pedicularis bracteosa	1 (1)	7 (1)	- (0)	- (0)	- (0)	3 (0)	- (0)	2 (1)	- (0)	- (0)
509	Pedicularis racemosa	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
513	Penstemon procerus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
669	Potentilla diversifolia	- (0)	6 (1)	- (0)	- (0)	- (0)	5 (1)	+ (1)	4 (2)	2 (1)	4 (1)
521	Potentilla flabellifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
670	Potentilla gracilis	2 (2)	2 (1)	- (0)	1 (1)	1 (1)	- (0)	+ (1)	- (0)	2 (1)	- (0)
702	Potentilla ovina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)	[illegible] (1)	1 (1)	- (0)
526	Pyrola asarifolia	3 (2)	- (0)	8 (1)	1 (3)	- (0)	- ([illegible])	- (0)	- (0)	- (0)	- (0)
529	Pyrola secunda	8 (2)	9 (4)	8 (1)	9 (1)	9 (4)	2 (3)	7 (1)	- (0)	4 (1)	7 (1)
676	Saxifraga arguta	7 (16)	7 (4)	5 (19)	1 (37)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
840	Senecio lugens	- (0)	3 (1)	3 (1)	1 (1)	- (0)	- ([illegible])	- ([illegible])	[illegible] (1)	1 ([illegible])	2 (1)
681	Senecio streptanthifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)	4 (2)	6 (1)	4 (0)
539	Senecio triangularis	7 (12)	6 (16)	3 (37)	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
541	Silene menziesii	- (0)	- (0)	- (0)	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
542	Smilacina racemosa	1 (3)	- (0)	3 (1)	1 (1)	4 (1)	- (0)	- (0)	- (0)	1 (1)	1 (0)
543	Smilacina stellata	5 (7)	- (0)	5 (1)	8 (11)	4 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
684	Solidago multiradiata	- (0)	- (0)	- (0)	- (0)	1 (1)	4 (2)	5 (3)	8 (1)	5 (1)	4 (1)
546	Streptopus amplexifolius	4 (8)	3 (22)	- (0)	3 (20)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
714	Thalictrum fendleri	2 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
547	Thalictrum occidentale	2 (2)	1 (15)	3 (1)	4 (5)	5 (8)	- (0)	+ (1)	- (0)	3 (3)	- (0)
690	Trollius laxus	2 (2)	9 (17)	- (0)	- (0)	- (0)	1 (0)	- (0)	- (0)	- (0)	- (0)
550	Valeriana dioica & occidentalis	1 (1)	1 (15)	3 (1)	- (0)	3 (1)	- (0)	- (0)	- (0)	1 (1)	1 (1)
554	Viola adunca	1 (1)	- (0)	- (0)	3 (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
555	Viola canadensis	1 (3)	1 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
693	Viola nuttallii	1 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
557	Viola orbiculata	2 (1)	- (0)	8 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
694	Viola purpurea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
558	Xerophyllum tenax	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)

(con.)

APPENDIX C-1

APPENDIX C-1

Constancy* and average canopy coverage (percent) of important plants in eastern Idaho-western Wyoming habitat types and phases.

ALP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	ABIES LASIOCARPA													
	HABITAT TYPE	CACA	ACRU	PHMA	ACGL	LIBO	LIBO	VAGL	VAGL	VAGL	VASC	VASC	VASC	ARLA	SYAL
	PHASE	CACA				LIBO	VASC	VAGL	PAMY	VASC	CARU	VASC	PIAL		
	NUMBER OF STANDS	n= 4	n=18	n= 8	n=23	n=15	n=11	n= 4	n=51	n=10	n= 5	n=61	n=27	n=21	n=11
	TREES														
002	Abies lasiocarpa	10 (34)	10 (29)	10 (25)	10 (25)	10 (15)	9 (14)	10 (21)	10 (27)	10 (30)	10 (19)	10 (25)	10 (19)	10 (28)	10 (23)
007	Picea engelmannii	10 (41)	9 (30)	6 (7)	6 (16)	9 (43)	9 (37)	8 (10)	8 (26)	10 (32)	2 (1)	9 (29)	9 (18)	10 (34)	6 (15)
008	Picea glauca	(0)	- (0)	- (0)	- (0)	1 (74)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (37)
022	Picea pungens	- (0)	2 (5)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
009	Pinus albicaulis	5 (1)	1 (3)	- (0)	+ (15)	1 (8)	4 (1)	5 (3)	1 (7)	5 (5)	2 (1)	2 (2)	10 (35)	2 (34)	- (0)
010	Pinus contorta	5 (15)	5 (8)	1 (3)	4 (18)	8 (22)	9 (32)	8 (31)	7 (31)	9 (18)	10 (38)	7 (35)	7 (26)	2 (17)	7 (21)
011	Pinus flexilis	3 (1)	- (0)	1 (15)	1 (1)	1 (1)	1 (15)	- (0)	1 (5)	1 (1)	- (0)	2 (7)	2 (38)	1 (9)	3 (0)
014	Populus tremuloides	- (0)	1 (3)	1 (37)	+ (3)	1 (63)	- (0)	- (0)	+ (15)	- (0)	2 (1)	- (0)	- (0)	1 (26)	3 (26)
016	Pseudotsuga menziesii	- (0)	5 (17)	10 (53)	9 (36)	5 (24)	4 (13)	8 (30)	6 (13)	1 (0)	4 (1)	1 (19)	+ (15)	3 (17)	8 (23)
	SHRUBS AND SUBSHRUBS														
102	Acer glabrum	- (0)	3 (8)	10 (8)	8 (23)	1 (1)	- (0)	- (0)	1 (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (2)
167	Acer grandidentatum	- (0)	- (0)	- (0)	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
104	Alnus sinuata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
105	Amelanchier alnifolia	3 (3)	3 (1)	9 (7)	9 (6)	1 (1)	- (0)	3 (1)	5 (6)	2 (8)	4 (1)	1 (1)	- (0)	- (0)	10 (9)
201	Arctostaphylos uva-ursi	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (3)	- (0)	- (0)	- (0)	2 (1)	+ (1)	- (0)	- (0)	2 (2)
150	Artemisia tridentata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)
203	Berberis repens	- (0)	4 (1)	6 (4)	7 (1)	5 (2)	2 (9)	3 (3)	1 (1)	2 (1)	2 (1)	1 (1)	+ (1)	- (0)	6 (4)
107	Ceanothus velutinus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
173	Cercocarpus ledifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
204	Clematis columbiana	- (0)	2 (5)	9 (4)	2 (3)	3 (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	3 (13)
112	Juniperus communis	- (0)	2 (1)	4 (1)	- (0)	7 (5)	5 (7)	- (0)	+ (1)	1 (1)	2 (1)	2 (6)	1 (6)	+ (1)	5 (4)
113	Juniperus horizontalis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
153	Ledum glandulosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
206	Linnaea borealis	- (0)	1 (15)	- (0)	- (0)	10 (35)	10 (21)	- (0)	+ (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
115	Lonicera utahensis	3 (15)	9 (5)	8 (6)	7 (13)	3 (4)	6 (4)	10 (9)	6 (10)	7 (10)	6 (2)	3 (2)	1 (1)	2 (1)	6 (2)
116	Menziesia ferruginea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
118	Pachistima myrsinites	3 (37)	7 (2)	10 (9)	10 (13)	1 (2)	1 (3)	- (0)	9 (3)	6 (4)	8 (1)	3 (6)	+ (15)	5 (3)	9 (4)
122	Physocarpus malvaceus	- (0)	1 (3)	10 (59)	2 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (3)
169	Physocarpus monogynus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
124	Prunus virginiana	- (0)	1 (3)	1 (1)	2 (5)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	5 (1)
125	Purshia tridentata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
128	Ribes cereum	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	+ (1)	- (0)
158	Ribes hudsonianum	- (0)	1 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
130	Ribes lacustre	3 (3)	7 (5)	3 (2)	2 (1)	3 (3)	3 (3)	- (0)	2 (2)	1 (1)	- (0)	1 (2)	+ (3)	- (0)	2 (1)
159	Ribes montigenum	- (0)	1 (2)	- (0)	1 (1)	1 (3)	1 (1)	3 (3)	1 (2)	1 (1)	- (0)	2 (2)	1 (2)	7 (4)	- (0)
131	Ribes viscosissimum	- (0)	3 (2)	- (0)	5 (2)	- (0)	2 (2)	5 (2)	3 (1)	- (0)	- (0)	1 (0)	- (0)	1 (1)	- (0)
132	Rosa acicularis	- (0)	1 (3)	- (0)	- (0)	5 (1)	- (0)	- (0)	+ (1)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)
161	Rosa nutkana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
134	Rosa woodsii	- (0)	1 (3)	1 (1)	3 (2)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	+ (1)	- (0)	1 (1)	1 (1)
136	Rubus parviflorus	- (0)	6 (7)	1 (3)	6 (5)	- (0)	- (0)	5 (3)	3 (2)	1 (1)	2 (1)	1 (1)	- (0)	1 (2)	- (0)
137	Salix scouleriana	- (0)	1 (15)	3 (1)	3 (6)	- (0)	- (0)	- (0)	+ (1)	1 (3)	- (0)	+ (1)	- (0)	1 (3)	1 (1)
139	Shepherdia canadensis	3 (3)	2 (1)	4 (1)	3 (7)	8 (4)	4 (15)	3 (1)	4 (7)	3 (5)	2 (3)	2 (9)	1 (1)	1 (1)	5 (4)
140	Sorbus scopulina	3 (3)	4 (9)	5 (6)	8 (13)	1 (1)	- (0)	8 (1)	7 (2)	4 (1)	4 (1)	2 (1)	- (0)	2 (1)	3 (1)
142	Spiraea betulifolia	3 (37)	3 (7)	8 (17)	3 (13)	3 (8)	2 (15)	10 (5)	4 (10)	1 (1)	2 (15)	+ (2)	- (0)	- (0)	3 (22)
143	Symphoricarpos albus	- (0)	2 (10)	5 (9)	- (0)	3 (10)	- (0)	- (0)	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	10 (15)
163	Symphoricarpos oreophilus	3 (3)	2 (1)	- (0)	4 (2)	1 (3)	1 (3)	3 (3)	1 (1)	- (0)	- (0)	+ (1)	- (0)	3 (1)	- (0)
145	Vaccinium caespitosum	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
146	Vaccinium globulare	5 (9)	4 (16)	- (0)	5 (31)	1 (2)	3 (7)	10 (16)	10 (49)	10 (32)	- (0)	2 (2)	2 (1)	1 (3)	1 (1)
148	Vaccinium scoparium	10 (33)	1 (15)	- (0)	2 (20)	2 (1)	10 (36)	5 (1)	3 (9)	10 (52)	10 (51)	10 (53)	10 (57)	2 (3)	1 (1)
	FERNS AND ALLIES														
254	Equisetum arvensis	3 (3)	1 (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)
	GRAMINOIDS														
301	Agropyron spicatum	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
338	Bromus ciliatus	3 (3)	4 (2)	1 (3)	2 (9)	3 (2)	2 (3)	- (0)	1 (4)	1 (1)	- (0)	1 (1)	- (0)	1 (2)	- (0)
304	Bromus vulgaris	- (0)	2 (5)	1 (1)	2 (11)	- (0)	1 (3)	5 (8)	1 (7)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (8)
305	Calamagrostis canadensis	10 (37)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	+ (1)	1 (0)	- (0)	1 (1)
307	Calamagrostis rubescens	- (0)	2 (4)	5 (5)	5 (11)	5 (26)	5 (6)	8 (11)	4 (25)	2 (37)	10 (38)	1 (2)	+ (0)	+ (1)	8 (28)
339	Carex disperma	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
309	Carex geyeri	3 (15)	3 (7)	- (0)	3 (9)	1 (2)	1 (1)	8 (11)	3 (8)	4 (2)	6 (6)	2 (11)	1 (11)	3 (7)	3 (14)
311	Carex rossii	- (0)	3 (1)	3 (1)	3 (1)	2 (1)	1 (1)	8 (1)	5 (2)	3 (1)	4 (2)	5 (1)	6 (2)	5 (1)	2 (1)
316	Elymus glaucus	5 (3)	3 (1)	3 (0)	4 (5)	3 (2)	4 (1)	5 (2)	3 (1)	5 (1)	2 (1)	1 (2)	3 (1)	- (0)	3 (5)
317	Festuca idahoensis	- (0)	- (0)	- (0)	(0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (1)
348	Hesperochloa kingii	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
[illegible]	Juncus drummondii	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)
[illegible]	Koeleria cristata	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
[illegible]	Luzula hitchcockii	(0)	- (0)	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
[illegible]	Luzula parviflora	3 (3)	1 (1)	- (0)	+ (3)	- (0)	- (0)	- (0)	+ (1)	1 (1)	- (0)	+ (1)	- (0)	- (0)	- (0)
[illegible]	Melica bulbosa	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
329	Oryzopsis asperifolia	- (0)	1 (3)	- (0)	- (0)	1 (8)	1 (15)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
331	Poa nervosa	- (0)	1 (3)	3 (1)	+ (1)	1 (15)	1 (1)	5 (2)	1 (1)	- (0)	2 (1)	3 (3)	3 (1)	4 (1)	2 (1)
360	Stipa occidentalis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)

*Code to constancy values: + = 0- 5% 1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45-55% 6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95-100%

(con.)

APPENDIX C-1

APPENDIX C-1 (con.)

ADP NO.	SERIES	ABIES LASIOCARPA													
	HABITAT TYPE	CACA	ACRU	PHMA	ACGL	LIBO	LIBO	VACL	VACL	VAGL	VASC	VASC	VASC	ARLA	SYAL
	PHASE	CACA				LIBO	VASC	VAGL	PAMY	VASC	CARU	VASC	PIAL		
	NUMBER OF STANDS	n= 4	n=18	n= 8	n=23	n=15	n=11	n= 4	n=51	n=10	n= 5	n=61	n=27	n=21	n=11
	FORBS														
401	Achillea millefolium	- (0)	- (0)	- (0)	2 (2)	3 (1)	- (0)	- (0)	1 (1)	- (0)	4 (1)	1 (1)	2 (1)	7 (1)	4 (1)
402	Actaea rubra	- (0)	10 (11)	1 (0)	2 (T)	4 (T)	- (0)	- (0)	1 (T)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (T)
565	Aconitum columbianum	3 (3)	1 (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
404	Allium cernuum	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
409	Antennaria anaphaloides	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
414	Antennaria microphylla	- (0)	- (0)	- (0)	- (0)	1 (8)	2 (0)	- (0)	1 (1)	- (0)	4 (1)	1 (1)	1 (5)	+ (3)	2 (1)
573	Antennaria parvifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
413	Antennaria racemosa	- (0)	1 (2)	- (0)	+ (1)	5 (3)	6 (3)	3 (0)	1 (7)	5 (1)	2 (1)	2 (3)	3 (3)	+ (1)	1 (1)
754	Aquilegia coerulea	3 (3)	4 (3)	1 (1)	3 (0)	3 (1)	3 (2)	- (0)	3 (1)	1 (1)	2 (1)	3 (1)	3 (3)	5 (1)	1 (1)
420	Arenaria macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
421	Arnica cordifolia	8 (10)	8 (7)	8 (4)	9 (5)	10 (8)	10 (11)	10 (15)	9 (8)	10 (3)	8 (6)	9 (7)	6 (11)	7 (4)	7 (11)
422	Arnica latifolia	- (0)	2 (6)	- (0)	+ (15)	- (0)	- (0)	- (0)	4 (18)	3 (1)	2 (1)	2 (7)	4 (7)	10 (18)	- (0)
426	Aster conspicuus	- (0)	2 (9)	5 (5)	1 (9)	7 (12)	5 (4)	8 (13)	1 (8)	2 (8)	- (0)	1 (1)	+ (3)	1 (8)	3 (33)
582	Aster engelmannii	3 (15)	6 (4)	4 (1)	7 (2)	2 (1)	1 (1)	8 (2)	6 (4)	2 (2)	4 (1)	2 (1)	3 (3)	6 (4)	2 (1)
822	Aster glaucodes	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)
430	Astragalus miser	- (0)	1 (1)	- (0)	- (0)	3 (2)	3 (1)	3 (1)	+ (1)	- (0)	4 (1)	1 (3)	2 (6)	1 (1)	2 (2)
817	Balsamorhiza macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
431	Balsamorhiza sagittata	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (2)
843	Balsamorhiza incana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
769	Caltha leptosepala	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)
436	Campanula rotundifolia	- (0)	- (0)	1 (1)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	2 (1)
438	Castilleja miniata	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	1 (1)	1 (1)	- (0)	+ (1)	+ (1)	- (0)	1 (0)
594	Castilleja rhexifolia	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (3)	1 (1)	- (0)
442	Chimaphila umbellata	- (0)	2 (0)	- (0)	4 (3)	1 (1)	- (0)	3 (3)	4 (2)	3 (1)	2 (3)	+ (1)	- (0)	- (0)	2 (1)
599	Clematis pseudoalpina	- (0)	- (0)	- (0)	- (0)	- (C)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
600	Clematis tenuiloba	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
602	Crepis acuminata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)
847	Cymopteris hendersonii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
455	Disporum trachycarpum	- (0)	3 (3)	9 (3)	4 (1)	3 (1)	1 (1)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	3 (1)
459	Epilobium angustifolium	8 (1)	4 (1)	5 (1)	3 (1)	8 (1)	6 (5)	5 (1)	3 (1)	5 (1)	6 (1)	6 (1)	6 (2)	3 (2)	9 (1)
465	Fragaria vesca	- (0)	6 (1)	9 (2)	5 (2)	6 (1)	2 (3)	5 (1)	2 (1)	3 (1)	2 (1)	2 (1)	1 (1)	1 (2)	3 (1)
466	Fragaria virginiana	8 (6)	3 (1)	- (0)	2 (5)	3 (4)	3 (1)	3 (3)	1 (1)	1 (1)	6 (1)	1 (1)	1 (1)	1 (2)	5 (1)
616	Frasera speciosa	- (0)	1 (1)	1 (1)	+ (1)	6 (1)	4 (1)	- (0)	1 (1)	- (0)	4 (1)	1 (2)	1 (1)	2 (1)	3 (1)
471	Galium triflorum	3 (1)	7 (4)	3 (3)	5 (3)	1 (1)	1 (3)	3 (1)	1 (1)	- (0)	- (0)	+ (1)	- (0)	- (0)	4 (1)
620	Geranium richardsonii	5 (2)	5 (3)	- (0)	2 (1)	3 (4)	4 (2)	5 (3)	1 (2)	- (0)	- (0)	1 (3)	1 (2)	- (0)	- (0)
473	Geranium viscosissimum	- (0)	1 (1)	- (0)	2 (8)	2 (1)	- (0)	3 (1)	1 (1)	- (0)	8 (5)	1 (1)	1 (1)	1 (1)	6 (3)
474	Geum triflorum	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)
476	Goodyera oblongifolia	- (0)	4 (1)	3 (1)	5 (1)	- (0)	- (0)	3 (3)	3 (1)	2 (1)	- (0)	1 (1)	+ (1)	+ (1)	1 (1)
481	Heracleum lanatum	- (0)	2 (1)	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)
484	Hieracium albiflorum	- (0)	3 (1)	1 (1)	4 (2)	- (0)	1 (3)	5 (1)	5 (1)	2 (1)	6 (1)	2 (1)	- (0)	2 (1)	4 (1)
486	Hieracium gracile	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	2 (2)	+ (1)	- (0)
756	Ligusticum filicinum	3 (3)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)	- (0)	2 (1)	1 (1)	- (0)	4 (1)	3 (1)
639	Linum perenne	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
641	Lupinus argenteus	- (0)	- (0)	- (0)	+ (1)	1 (1)	1 (3)	- (0)	1 (1)	- (0)	6 (1)	1 (6)	1 (13)	1 (1)	3 (1)
649	Mitella pentandra	3 (15)	1 (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
502	Mitella stauropetala	3 (3)	6 (1)	6 (1)	7 (1)	- (0)	1 (1)	- (0)	2 (1)	1 (1)	- (0)	1 (1)	- (0)	1 (1)	- (0)
505	Osmorhiza chilensis	3 (3)	7 (4)	4 (6)	5 (9)	3 (2)	5 (2)	8 (7)	4 (3)	2 (2)	- (0)	2 (1)	1 (0)	5 (1)	3 (1)
653	Osmorhiza depauperata	3 (3)	4 (1)	1 (1)	5 (9)	4 (1)	1 (1)	3 (3)	5 (3)	4 (1)	4 (1)	3 (1)	2 (1)	3 (2)	5 (1)
507	Pedicularis bracteosa	- (0)	1 (1)	1 (1)	1 (1)	1 (3)	1 (1)	5 (3)	1 (1)	3 (0)	4 (1)	2 (1)	4 (4)	+ (1)	2 (2)
509	Pedicularis racemosa	3 (3)	4 (2)	3 (1)	5 (9)	- (0)	1 (1)	5 (8)	6 (4)	5 (2)	4 (1)	5 (5)	3 (1)	8 (4)	2 (1)
513	Penstemon procerus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
669	Potentilla diversifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (3)	- (0)	- (0)
521	Potentilla flabellifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
670	Potentilla gracilis	3 (3)	1 (3)	- (0)	- (0)	1 (2)	- (0)	- (0)	+ (1)	- (0)	- (0)	+ (0)	+ (1)	1 (1)	2 (1)
702	Potentilla ovina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
526	Pyrola asarifolia	5 (1)	2 (2)	- (0)	1 (1)	1 (3)	2 (2)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
529	Pyrola secunda	10 (2)	8 (3)	8 (1)	9 (3)	8 (1)	9 (2)	8 (3)	7 (3)	7 (2)	4 (1)	6 (2)	4 (1)	6 (3)	5 (1)
676	Saxifraga arguta	3 (15)	2 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (0)	- (0)	- (0)	- (0)
840	Senecio lugens	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
681	Senecio streptanthifolius	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)
539	Senecio triangularis	3 (3)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (0)	- (0)	+ (0)	+ (1)	- (0)	- (0)
541	Silene menziesii	- (0)	- (0)	- (0)	3 (1)	- (0)	- (0)	- (0)	1 (2)	- (0)	- (0)	- (0)	- (0)	1 (2)	1 (0)
542	Smilacina racemosa	- (0)	2 (1)	6 (1)	3 (1)	2 (1)	- (0)	3 (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	4 (1)
543	Smilacina stellata	3 (3)	3 (4)	1 (1)	+ (1)	2 (1)	- (0)	- (0)	+ (1)	- (0)	- (0)	+ (1)	+ (0)	- (0)	- (0)
684	Solidago multiradiata	- (0)	1 (1)	- (0)	- (0)	3 (1)	2 (2)	3 (1)	+ (1)	- (0)	- (0)	3 (1)	1 (0)	1 (1)	- (0)
546	Streptopus amplexifolius	5 (1)	1 (3)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (0)	- (0)	+ (0)	1 (1)
714	Thalictrum fendleri	3 (37)	4 (5)	4 (5)	5 (5)	1 (1)	- (0)	3 (1)	4 (4)	2 (1)	2 (15)	1 (3)	1 (19)	1 (2)	3 (1)
547	Thalictrum occidentale	- (0)	4 (7)	4 (1)	1 (11)	4 (2)	3 (2)	5 (15)	1 (3)	2 (3)	- (0)	1 (2)	- (0)	- (0)	2 (2)
690	Trollius laxus	3 (3)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	+ (1)	- (0)	- (0)	- (0)
550	Valeriana dioica & occidentalis	- (0)	1 (3)	- (0)	- (0)	2 (1)	1 (3)	- (0)	+ (3)	- (0)	- (0)	+ (1)	+ (1)	+ (1)	1 (1)
554	Viola adunca	- (0)	2 (2)	4 (1)	4 (1)	1 (2)	- (0)	3 (3)	2 (3)	- (0)	8 (1)	+ (0)	- (0)	- (0)	5 (1)
555	Viola canadensis	- (0)	- (0)	1 (0)	1 (1)	- (0)	- (0)	5 (2)	+ (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	1 (1)
693	Viola nuttallii	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	+ (1)	- (0)	2 (1)	+ (1)	- (0)	1 (1)	- (0)
557	Viola orbiculata	- (0)	1 (1)	1 (1)	+ (3)	- (0)	- (0)	- (0)	+ (2)	2 (1)	- (0)	+ (1)	- (0)	- (0)	- (0)
694	Viola purpurea	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
558	Xerophyllum tenax	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)

(con.)

APPENDIX C-1

APPENDIX C-1

Constancy* and average canopy coverage (percent) of important plants in eastern Idaho-western Wyoming habitat types and phases.

ADP No.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	TH[illegible] n=16	OSCH OSCH n=[illegible]	OSCH PAMY n=[illegible]	SPBE n=[illegible]	CARU CARU n=16	CARU PAMY n=6	BERE BERE n=48	JUCO n=8	RIMO RIMO n=10	RIMO PIAL n=8	PERA n=18	ARCO PIEN n=12	ARCO SHCA n=10	ARCO ARCO n=17	ARCO ASMI n=11	CARO n=4[illegible]
		ABIES LASIOCARPA															
	TREES																
[illegible]	Abies lasiocarpa	[illegible] (31)	10 (30)	10 (31)	10 (27)	10 (25)	10 (20)	10 (26)	10 (20)	10 (50)	10 (44)	10 (53)	10 (24)	10 (19)	10 (35)	9 (21)	10 (4[illegible]
007	Picea engelmannii	[illegible] (2)	[illegible] (26)	4 (15)	5 (11)	3 (4)	3 (3)	4 (20)	5 (23)	5 (43)	4 (17)	7 (17)	10 (55)	3 (7)	5 (7)	5 (3)	3 (
008	Picea glauca	- ([illegible])	(3)	- ([illegible])	1 (3[illegible])	- (0)	- (0)	- (0)	1 (37)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
022	Picea pungens	- (1)	(0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Pinus albicaulis	[illegible]	- (0)	[illegible] (26)	- (0)	+ (3)	- (0)	+ (15)	1 (63)	2 (6)	10 (63)	2 (6)	2 (26)	3 (14)	2 (1)	- (0)	- (
[illegible]	Pinus contorta	6 (2)	4 (36)	3 (34)	7 (22)	9 (35)	5 (26)	6 (31)	9 (23)	4 (8)	- (0)	9 (25)	8 (16)	10 (42)	8 (35)	10 (38)	10 (2
011	Pinus flexilis	2 (1)	- (0)	1 (15)	- (0)	1 (1)	2 (2)	3 (11)	4 (2)	1 (1)	- (0)	1 (8)	1 (1)	3 (5)	3 (25)	6 (7)	3 (
014	Populus tremuloides	2 ([illegible]3)	3 (44)	4 ([illegible]3)	- (0)	3 (11)	3 (15)	2 (27)	1 (1)	- (0)	- (0)	- (0)	- (0)	3 (1)	1 (50)	- (0)	3 (
[illegible]	Pseudotsuga menziesii	5 (33)	6 (39)	9 (29)	[illegible] (35)	5 (33)	10 (42)	8 (37)	5 (13)	1 (0)	- (0)	4 (23)	2 (31)	5 (4)	2 (32)	1 (63)	- (
	SHRUBS AND SUBSHRUBS																
[illegible]	Acer glabrum	- (0)	1 (1)	4 (2)	4 (2)	- (0)	3 (2)	1 (2)	- (0)	- (0)	- (0)	1 (3)	- (0)	1 (1)	- (0)	- (0)	- (
[illegible]	Acer grandidentatum	1 (1)	- (0)	1 (3)	- (0)	- (0)	- (0)	+ (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Alnus sinuata	- (0)	[illegible] (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Amelanchier alnifolia	2 (1)	3 (2)	4 (5)	6 (5)	6 (1)	7 (6)	5 (4)	1 (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Arctostaphylos uva-ursi	- (0)	- ([illegible])	- (0)	- (0)	- (0)	- (0)	+ (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	3 (1)	- (0)	1 (1)	- (
[illegible]	Artemisia tridentata	[illegible] (1)	+ ([illegible])	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (1)	4 (T)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
203	Berberis repens	5 (3)	4 (8)	6 (2)	6 (1)	3 (1)	8 ([illegible])	9 (3)	3 (T)	- (0)	- (0)	2 (T)	1 (T)	4 (T)	1 (T)	4 (T)	- (
107	Ceanothus velutinus	- (0)	+ (0)	- (0)	1 (1)	- (0)	2 (1)	1 (6)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
173	Cercocarpus ledifolius	(0)	- (0)	- (0)	- (0)	- (0)	2 (3)	+ (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Clematis columbiana	[illegible] (3)	- ([illegible])	1 (1)	5 (3)	1 (1)	3 (2)	+ (1)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (
[illegible]	Juniperus communis	3 (5)	- (0)	- (0)	2 (2)	1 (1)	- (0)	2 (2)	10 (19)	- (0)	- (0)	1 (1)	4 (2)	6 (1)	1 (3)	5 (2)	- (
113	Juniperus horizontalis	(0)	- ([illegible])	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Ledum glandulosum	- (0)	- ([illegible])	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
206	Linnaea borealis	(0)	- ([illegible])	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	1 (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
115	Lonicera utahensis	3 (5)	+ ([illegible])	3 ([illegible])	8 (4)	3 (1)	5 (11)	[illegible] (5)	1 (1)	1 (1)	- (0)	3 (2)	1 (1)	1 (1)	2 (1)	1 (1)	- (
[illegible]	Menziesia ferruginea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
118	Pachistima myrsinites	1 (9)	5 ([illegible])	10 (21)	8 (9)	4 (1)	10 (35)	9 (13)	1 (1)	5 (2)	2 (T)	7 (1)	1 (1)	2 (1)	5 (1)	5 (0)	- (
122	Physocarpus malvaceus	(0)	[illegible]	- (0)	(0)	(0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
169	Physocarpus monogynus	[illegible] (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
124	Prunus virginiana	- (0)	[illegible] (1)	2 (19)	- (0)	- (0)	- (0)	2 (5)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
125	Purshia tridentata	(0)	(0)	- (0)	(0)	- (0)	2 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
128	Ribes cereum	(0)	[illegible] (1)	(0)	(0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)	- (
158	Ribes hudsonianum	- ([illegible])	(0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0	- (0)	- (
[illegible]	Ribes lacustre	3 (1)	+ (1)	- (0)	1 (1)	1 (8)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (15)	- (0)	1 (	- (0)	- (
[illegible]	Ribes montigenum	4 (3)	3 (2)	3 (7)	3 (2)	1 (1)	- (0)	2 (2)	- (0)	10 (19)	10 (23)	4 (2)	5 (1)	2 (1)	6	2 (1)	- (
131	Ribes viscosissimum	1 ([illegible])	4 (2)	2 (1)	4 (1)	[illegible] (1)	3 (1)	3 (1)	- (0)	- (0)	- (0)	3 (1)	- (0)	1 (1)	1	1 (1)	5 (
132	Rosa [illegible]	(6)	- (0)	([illegible])	1 ([illegible]5)	1 (9)	- (0)	+ (1)	3 (1)	- (0)	- (0)	- (0)	2 (8)	- (0)	[illegible]	2 (1)	- (
[illegible]	Rosa nutkana	([illegible])	([illegible])	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	[illegible]	- (0)	- (0)	- (
[illegible]	Rosa woodsii	1 [illegible]	[illegible] (1)	4 ([illegible])	- (0)	1 ([illegible])	[illegible] (3)	4 (1)	1 (1)	- (0)	- (0)	2 (1)	2 (1)	1 (1)	1 (1)	1 (1)	- (
[illegible]	Rubus parviflorus	1 ([illegible])	- (0)	3 (1)	3 (3)	1 (1)	[illegible] (3)	[illegible] (1)	- (0)	- (0)	- (0)	- ([illegible])	- (0)	- ([illegible])	- (0)	- (0)	- (
[illegible]	[illegible]	- ([illegible])	[illegible] (0)	2 ([illegible])	1 (1)	[illegible] (3)	7 (3)	[illegible] (5)	- (0)	- (0)	- (0)	1 (1)	- (0)	1 (3)	- (0)	- (0)	- (
139	Shepherdia canadensis	[illegible] (4)	+ (3)	2 (20)	5 (4)	1 (2)	5 (1)	5 (6)	8 (10)	- (0)	1 (T)	4 (3)	4 (20)	10 (33)	2 (1)	5 (1)	- (
140	Sorbus scopulina	[illegible]	+ (5)	7 (1)	6 ([illegible])	[illegible] (1)	3 (3)	4 (3)	- (0)	1 (3)	- (0)	2 (1)	- (0)	1 (1)	1 (1)	- (0)	- (
[illegible]	Spiraea betulifolia	2 (7)	([illegible])	- (0)	10 (34)	1 (1)	3 (2)	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (
[illegible]	Symphoricarpos albus	[illegible]	- ([illegible])	- (0)	- (0)	3 (2)	(0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Symphoricarpos oreophilus	4 ([illegible])	8 ([illegible])	7 (6)	4 (2)	6 (2)	7 (1)	8 (5)	- (0)	3 (1)	- (0)	5 (1)	- (0)	2 (1)	3 (1)	1 (1)	5 (1
[illegible]	Vaccinium caespitosum	- ([illegible])	(0)	- (0)	- (0)	1 (1)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
146	Vaccinium globulare	1 (1)	- (0)	(0)	3 (1)	1 (1)	2 (1)	+ (1)	- (0)	- (0)	- (0)	2 (1)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Vaccinium scoparium	1 (3)	- (0)	(0)	1 ([illegible])	1 (1)	- (0)	(0)	- (0)	2 (1)	1 (T)	- (0)	3 (0)	1 (3)	- (0)	- (0)	- (
	FERNS AND ALLIES																
[illegible]	Equisetum arvense	1 (1)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
	GRAMINOIDS																
[illegible]	Agropyron spicatum	(0)	+ (15)	1 (1)	[illegible] (1)	(0)	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Bromus ciliatus	3 (5)	+ (1)	1 ([illegible])	[illegible] (1)	1 (1)	- (0)	1 (0)	1 (1)	- (0)	- (0)	- (0)	3 (4)	1 (1)	1 (1)	- (0)	- (
304	Bromus vulgaris	1 (3)	(0)	(0)	[illegible] (3)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (
[illegible]	Calamagrostis canadensis	- ([illegible])	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (
[illegible]	Calamagrostis rubescens	6 (8)	3 ([illegible]0)	4 ([illegible]1)	4 (1[illegible])	10 (46)	10 (68)	1 (2)	1 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	3 (1
[illegible]	Carex disperma	- (0)	- ([illegible])	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0
[illegible]	Carex geyeri	4 (15)	[illegible] (8)	1 (37)	[illegible] (3[illegible])	4 (12)	- (0)	1 (1)	1 (3)	1 (3)	1 (T)	2 (1)	- (0)	1 (3)	1 (19)	- (0)	- (0
[illegible]	Carex rossii	3 ([illegible])	[illegible]	[illegible] (2)	4 (1)	3 (2)	2 (1)	5 (1)	6 (2)	5 (4)	8 (1)	7 (3)	3 (1)	2 (1)	7 (4)	9 (2)	10 (17
[illegible]	Elymus glaucus	([illegible])	2 [illegible]	6 ([illegible])	3 (1)	2 (1)	- (0)	3 (2)	- (0)	- (0)	- (0)	1 (1)	1 (0)	- (0)	2 (1)	1 (1)	- (0
317	Festuca idahoensis	([illegible])	(0)	- (0)	(0)	1 (3)	- (0)	1 (1)	- (0)	1 (1)	1 (T)	- ([illegible])	[illegible] (2)	2 (1)	1 (3)	- (0)	- (0
[illegible]	Hesperochloa kingii	([illegible])	(0)	- (0)	(0)	- (0)	- (0)	+ (2)	3 (1)	1 (1)	6 (T)	[illegible] (0)	- (0)	1 (1)	- (0)	1 (1)	- (0
[illegible]	Juncus drummondii	[illegible]	- (0)	- ([illegible])	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0
[illegible]	Koeleria cristata	([illegible])	(0)	- (0)	(0)	- (0)	- (0)	- (0)	4 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0
[illegible]	Luzula hitchcockii	([illegible])	(0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0
326	Luzula parviflora	- ([illegible])	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0
[illegible]	Melica bulbosa	1 (3)	- (0)	1 (3)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0
[illegible]	Oryzopsis asperifolia	([illegible])	(0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0
[illegible]	Poa nervosa	3 (8)	1 (4)	[illegible] (1)	3 (1)	3 (2)	3 (1)	3 (5)	4 (5)	2 (1)	- (0)	3 (1)	5 (4)	3 (1)	5 (5)	4 (5)	3 (1
[illegible]	Stipa occidentalis	1 ([illegible])	[illegible] (0)	- (0)	(0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)	- (0)	1 (1)	- (0

(con.

*Code to constancy values: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

APPENDIX C-1 (con.)

SERIES	ABIES LASIOCARPA															
HABITAT TYPE	THOC	OSCH	OSCH	SPBE	CARU	CARU	BERE	LUCO	RIMO	RIMO	PERA	ARCO	[illegible]	[illegible]	ARCO	[illegible]
PHASE		OSCH	PAMY		CARU	PAMY	BERE		RIMO	PIAL		PIEN	[illegible]	[illegible]	ASMI	
NUMBER OF STANDS	n=16	n=23	n= 9	n=11	n=16	n= 6	n=48	n= 8	n=10	n= 8	n=18	n=1[illegible]	n=10	n=17	n=11	n= 4
FORBS																
Achillea millefolium	3 (5)	3 (2)	2 (1)	- (0)	5 (1)	[illegible] (1)	2 (1)	3 (1)	4 (1)	6 (1)	(1)	4 (1)	[illegible]	[illegible]	[illegible]	[illegible]
Actaea rubra	1 (T)	1 (T)	1 (1)	2 (T)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	(0)	- (0)	( )	- ( )	- (0)	(0)
Aconitum columbianum	- (0)	- (0)	- (0)	- (0)	1 (37)	- (0)	- (0)	- (0)	- (0)	( )	(0)	- (0)	( )	1 (1)	- (0)	(0)
Allium cernuum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	(0)	- (0)	(0)	- (0)	(0)	(0)
Antennaria anaphaloides	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	( )	- (0)	- (0)	- (0)
Antennaria microphylla	- (0)	- (0)	- (0)	1 (1)	1 (1)	2 (1)	+ (1)	5 (1)	1 (1)	1 (T)	(0)	3 (0)	( )	2 (1)	5 (8)	3 (1)
Antennaria parvifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (3)	- ( )	- (0)	- (0)	- ( )	- (0)	(0)	1 (1)	( )	(0)
Antennaria racemosa	2 (6)	- (0)	- (0)	1 (3)	1 (3)	2 (3)	1 (4)	4 (2)	- (0)	- (0)	- (0)	3 (3)	(1)	( )	3 ( )	( )
Aquilegia coerulea	2 (11)	5 (1)	7 (4)	4 (1)	1 (2)	- (0)	4 (1)	1 (1)	5 (3)	3 (T)	4 (1)	6 (1)	( )	3 (4)	( )	- ( )
Arenaria macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	( )	- ( )	- (0)	- ( )
Arnica cordifolia	10 (15)	6 (11)	8 (1)	9 (9)	9 (10)	8 (7)	9 (15)	10 (7)	6 (3)	3 (T)	9 (7)	10 (15)	10 (6)	10 (17)	10 ( )	8 (1)
Arnica latifolia	- (0)	+ (1)	3 (1)	- (0)	- (0)	- (0)	1 (2)	- (0)	1 ( )	- (0)	2 (1)	1 (3)	- ( )	- (0)	( )	(0)
Aster conspicuus	4 (20)	- (0)	- (0)	2 (15)	2 (14)	- (0)	1 ( )	- (0)	- (0)	- (0)	1 ( )	1 (1)	( )	( )	( )	(0)
Aster engelmannii	4 (9)	4 (3)	8 (2)	5 (2)	4 (1)	5 (1)	5 (4)	1 (1)	3 (1)	4 (T)	8 (1)	- (0)	1 (1)	4 (1)	1 (1)	5 (1)
Aster glaucodes	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	1 ( )	- (0)	4 (1)	1 (1)	1 (1)	- (0)
Astragalus miser	4 (2)	- (0)	- (0)	4 (1)	1 (2)	- (0)	1 (12)	6 (7)	- (0)	- (0)	- ( )	4 (3)	(14)	1 (1)	10 (14)	(0)
Balsamorhiza macrophylla	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (3)	- (0)	(0)	(0)	- (0)	- (0)	- (0)	- (0)
Balsamorhiza sagittata	1 (1)	- (0)	- (0)	- (0)	- (0)	(0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	- (0)	(1)	(0)
Balsamorhiza incana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	(0)	(0)
Caltha leptosepala	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	(0)	(0)	- ( )	(0)	- ( )	(0)
Campanula rotundifolia	1 (1)	- (0)	- (0)	1 (1)	1 (1)	- (0)	1 (1)	3 (1)	- (0)	- (0)	- (0)	1 (1)	( )	. (1)	4 ( )	- (0)
Castilleja miniata	1 (1)	- (0)	- (0)	- (0)	1 (1)	2 (1)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	1 (1)	- (0)	- ( )
Castilleja rhexifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	( )	- (0)	- (0)	- (0)
Chimaphila umbellata	1 (1)	+ (3)	- (0)	2 (1)	1 (1)	3 (8)	2 (4)	- (0)	- (0)	- (0)	1 (3)	(0)	( )	1 (1)	- (0)	- (0)
Clematis pseudoalpina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	( )	- (0)	- (0)	- (0)
Clematis tenuiloba	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- ( )	- ( )	(0)	( )	(0)
Crepis acuminata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (3)	- (0)	- (0)	- (0)	- (0)	- (0)	( )	· (0)	(0)	- (0)
Cymopteris hendersonii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	(0)	- ( )	- (0)	- (0)	(0)
Disporum trachycarpum	1 (2)	1 (1)	2 (1)	3 (1)	1 (1)	3 (2)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	1 (1)	- ( )	( )
Epilobium angustifolium	6 (5)	2 (1)	7 (1)	5 (1)	4 (1)	5 (1)	3 (1)	9 (1)	4 (10)	- (0)	3 (1)	8 (3)	7 (1)	5 (1)	2 (2)	3 (1)
Fragaria vesca	3 (5)	3 (2)	3 (7)	5 (1)	4 (2)	3 (2)	5 (3)	- (0)	1 (1)	- (0)	3 (1)	(1)	- ( )	4 ( )	3 (1)	(0)
Fragaria virginiana	3 (2)	1 (2)	2 (15)	2 (1)	4 (3)	- (0)	1 (4)	5 (1)	1 (1)	- (0)	(1)	3 (1)	( )	. (13)	( )	( )
Frasera speciosa	2 (2)	2 (1)	2 (1)	2 (2)	3 (2)	2 (1)	2 (1)	5 (1)	1 (1)	3 (T)	(1)	( )	1 (1)	4 ( )	4 ( )	3 (1)
Galium triflorum	- (0)	1 (1)	2 (8)	2 (1)	2 (1)	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)
Geranium richardsonii	6 (14)	1 (1)	1 (1)	- (0)	1 (1)	- (0)	+ (8)	- (0)	- (0)	- (0)	- (0)	(0)	- ( )	1 (3)	1 ( )	3 (1)
Geranium viscosissimum	2 (5)	+ (1)	3 (11)	7 (1)	5 (3)	2 (3)	2 (2)	1 (1)	4 (1)	4 (T)	4 (1)	1 (1)	5 ( )	6 (1)	7 ( )	(1)
Geum triflorum	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	2 (1)	2 ( )	1 ( )	- (0)	- (0)
Goodyera oblongifolia	2 (1)	1 (1)	1 (1)	5 (1)	2 (1)	7 (1)	2 (1)	- (0)	- (0)	- (0)	+ (1)	- (0)	- ( )	1 (1)	- (0)	- ( )
Heracleum lanatum	1 (1)	- (0)	- (0)	- (0)	1 (37)	- (0)	- (0)	- (0)	1 (1)	- ( )	- (0)	- (0)	( )	- (0)	- ( )	- ( )
Hieracium albiflorum	1 (1)	3 (3)	1 (1)	5 (1)	4 (1)	3 (2)	3 (1)	1 (1)	- (0)	- (0)	3 (1)	- (0)	( )	4 (1)	5 (1)	3 (1)
Hieracium gracile	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	. (1)	(0)	( )	- (0)	(0)	- (0)
Ligusticum tenuifolium	1 (1)	2 (2)	2 (1)	2 (1)	1 (1)	2 (1)	1 (1)	- (0)	- (0)	- (0)	3 (1)	1 (3)	- (0)	1 (1)	- (0)	- (0)
Linum perenne	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	(0)	- (0)	- ( )	(0)
Lupinus argenteus	1 (9)	1 (2)	1 (1)	- (0)	3 (1)	3 (8)	+ (2)	- (0)	3 (1)	3 (1)	1 (1)	(1)	4 (1)	4 (5)	4 (5)	( )
Mitella pentandra	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- ( )	- (0)	- (0)
Mitella stauropetala	- (0)	3 (3)	7 (1)	2 (1)	2 (1)	2 (1)	3 (1)	- (0)	2 (1)	- (0)	11 (2)	1 (1)	- (0)	1 (1)	- (0)	(0)
Osmorhiza chilensis	9 (8)	7 (15)	1 (15)	3 (1)	5 (1)	7 (1)	6 (2)	- (0)	2 (2)	3 (T)	5 (1)	. (2)	- (0)	1 (3)	1 (0)	8 (1)
Osmorhiza depauperata	1 (1)	3 (19)	9 (15)	4 (2)	3 (1)	3 (1)	4 (2)	3 (1)	6 (1)	- (0)	4 (1)	(1)	(1)	6 ( )	5 (1)	(1)
Pedicularis bracteosa	3 (3)	+ (1)	- (0)	1 (1)	3 (1)	2 (1)	+ (0)	- (0)	2 (1)	1 (T)	1 (1)	(0)	- (0)	( )	- (0)	- (0)
Pedicularis racemosa	3 (10)	3 (7)	1 (3)	2 (2)	4 (4)	2 (1)	5 (5)	- (0)	3 (1)	1 (T)	10 (10)	1 (T)	1 (T)	. (T)	(T)	(0)
Penstemon procerus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	- ( )	- (0)	- (0)
Potentilla diversifolia	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	2 (0)	(0)	- (0)	- (0)	- (0)
Potentilla flabellifolia	- (0)	- (0)	- (0)	- (0)	1 (15)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	( )
Potentilla gracilis	5 (5)	1 (2)	- (0)	4 (1)	1 (1)	- (0)	+ (0)	3 (1)	1 (1)	3 (T)	- (0)	(1)	(1)	2 (1)	( )	- (0)
Potentilla ovina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- (0)	- (0)	- ( )	- (0)
Pyrola asarifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	+ (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	- (0)	(0)	- ( )
Pyrola secunda	4 (2)	2 (1)	4 (5)	6 (1)	5 (1)	7 (1)	6 (2)	6 (1)	3 (5)	- (0)	6 (2)	9 (4)	( )	4 (1)	7 ( )	5 (8)
Saxifraga arguta	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	( )	- (0)	- ( )	(0)
Senecio lugens	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (3)	- (0)	1 (1)	- (0)	(0)
Senecio streptanthifolius	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- (0)	3 (T)	1 (1)	3 (1)	- (0)	- (0)	(0)	(0)
Senecio triangularis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	(0)	(0)	( )	- (0)	- (0)
Silene menziesii	- (0)	6 (5)	3 (1)	- (0)	4 (1)	- (0)	4 (1)	- (0)	1 (1)	- (0)	2 (1)	- (0)	(0)	2 (1)	2 (1)	3 (3)
Smilacina racemosa	1 (2)	4 (1)	2 (1)	1 (1)	1 (1)	5 (1)	2 (1)	- (0)	1 (1)	- (0)	1 (1)	1 (1)	- (0)	- (0)	- (0)	(0)
Smilacina stellata	3 (5)	+ (3)	- (0)	1 (1)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	(0)	- (0)
Solidago multiradiata	4 (1)	- (0)	- (0)	- (0)	1 (3)	- (0)	+ (1)	6 (1)	2 (1)	4 (T)	- (0)	6 (1)	6 (1)	(1)	4 ( )	3 (1)
Streptopus amplexifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	(0)	- (0)	- (0)	- ( )	(0)	- (0)	- (0)
Thalictrum fendleri	- (0)	6 (6)	7 (5)	2 (3)	4 (1)	3 (1)	6 (4)	- (0)	1 (3)	- (0)	4 (1)	1 (1)	- (0)	3 (1)	1 (1)	3 (1)
Thalictrum occidentale	10 (28)	+ (1)	2 (2)	3 (1)	1 (2)	- (0)	1 (1)	- (0)	- (0)	- (0)	1 (1)	1 (1)	- ( )	1 (3)	- (0)	- (0)
Trollius laxus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- ( )	- (0)
Valeriana dioica and occidentalis	4 (2)	2 (2)	2 (1)	- (0)	1 (3)	- (0)	1 (1)	- (0)	1 (1)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)
Viola adunca	3 (2)	7 (3)	6 (2)	3 (1)	8 (1)	2 (1)	3 (2)	1 (1)	1 (1)	- (0)	2 (1)	2 (1)	1 (1)	1 (1)	- (0)	3 (1)
Viola canadensis	1 (3)	1 (1)	- (0)	1 (1)	- (0)	- (0)	+ (8)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
Viola nuttallii	- (0)	2 (1)	- (0)	- (0)	1 (1)	- (0)	1 (1)	- (0)	2 (1)	- (0)	2 (1)	- (0)	(0)	3 (1)	2 (1)	5 (2)
Viola orbiculata	1 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
Viola purpurea	- (0)	+ (1)	- (0)	- (0)	- (0)	- (0)	1 (2)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
Xerophyllum tenax	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)

(con.)

APPENDIX C-1

APPENDIX C-1

Constancy* and average canopy coverage (percent) of important plants in eastern Idaho-western Wyoming habitat types and phases

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PINUS ALBICAULIS						
		VASC n= 9	CAGE n= 3	JUCO SHCA n= 3	JUCO JUCO n=15	CARO PICO n=17	CARO CARO n= 3	FEID n= 3
	TREES							
002	Abies lasiocarpa	3 (4)	3 (1)	- (0)	1 (0)	2 (3)	3 (1)	- (0)
007	Picea engelmannii	4 (2)	- (0)	3 (1)	1 (0)	- (0)	7 (1)	3 (3)
008	Picea glauca	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
022	Picea pungens	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
009	Pinus albicaulis	10 (51)	10 (34)	10 (1)	7 (15)	9 (22)	10 (70)	10 (38)
010	Pinus contorta	9 (33)	3 (63)	10 (48)	10 (50)	10 (49)	- (0)	3 (3)
011	Pinus flexilis	- (0)	- (0)	3 (3)	1 (8)	2 (1)	- (0)	- (0)
014	Populus tremuloides	- (0)	- (0)	6 (1)	1 (0)	1 (1)	- (0)	3 (0)
016	Pseudotsuga menziesii	- (0)	3 (3)	3 (0)	1 (0)	- (0)	- (0)	- (0)
	SHRUBS and SUBSHRUBS							
102	Acer glabrum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
167	Acer grandidentatum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
104	Alnus sinuata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
105	Amelanchier alnifolia	- (0)	- (0)	3 (1)	1 (1)	- (0)	- (0)	- (0)
201	Arctostaphylos uva-ursi	- (0)	- (0)	3 (1)	5 (4)	1 (0)	- (0)	- (0)
150	Artemisia tridentata	- (0)	3 (1)	- (0)	- (0)	1 (0)	- (0)	3 (3)
203	Berberis repens	- (0)	- (0)	7 (1)	- (0)	- (0)	- (0)	- (0)
107	Ceanothus velutinus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
173	Cercocarpus ledifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
204	Clematis columbiana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
112	Juniperus communis	2 (3)	3 (1)	10 (1)	7 (5)	4 (0)	3 (0)	3 (0)
153	Juniperus horizontalis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
113	Ledum glandulosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
206	Linnaea borealis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
115	Lonicera utahensis	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
116	Menziesia ferruginea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
118	Pachistima myrsinites	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
122	Physocarpus malvaceus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
169	Physocarpus monogynus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
124	Prunus virginiana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
125	Purshia tridentata	- (0)	- (0)	- (0)	2 (5)	- (0)	- (0)	- (0)
128	Ribes cereum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
158	Ribes hudsonianum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
130	Ribes lacustre	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
159	Ribes montigenum	1 (3)	- (0)	- (0)	1 (1)	1 (0)	3 (1)	3 (3)
131	Ribes viscosissimum	- (0)	- (0)	3 (1)	1 (1)	- (0)	- (0)	- (0)
132	Rosa acicularis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
161	Rosa nutkana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
134	Rosa woodsii	- (0)	- (0)	- (0)	2 (1)	- (0)	- (0)	- (0)
136	Rubus parviflorus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
137	Salix scouleriana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
139	Shepherdia canadensis	- (0)	- (0)	10 (8)	5 (1)	1 (1)	- (0)	- (0)
140	Sorbus scopulina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
142	Spiraea betulifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
143	Symphoricarpos albus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
163	Symphoricarpos oreophilus	- (0)	3 (3)	- (0)	- (0)	1 (1)	- (0)	- (0)
145	Vaccinium caespitosum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
146	Vaccinium globulare	2 (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
148	Vaccinium scoparium	10 (41)	- (0)	- (0)	1 (0)	2 (0)	3 (0)	3 (1)
	FERNS and ALLIES							
254	Equisetum arvensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
	GRAMINOIDS							
301	Agropyron spicatum	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	7 (1)
338	Bromus ciliatus	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)	- (0)
304	Bromus vulgaris	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
305	Calamagrostis canadensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
307	Calamagrostis rubescens	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
339	Carex disperma	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
309	Carex geyeri	2 (33)	10 (38)	- (0)	- (0)	1 (2)	- (0)	- (0)
311	Carex rossii	7 (1)	3 (3)	3 (1)	8 (1)	9 (3)	7 (0)	3 (1)
316	Elymus glaucus	2 (2)	3 (3)	- (0)	- (0)	- (0)	- (0)	- (0)
317	Festuca idahoensis	1 (1)	10 (3)	3 (1)	2 (1)	4 (1)	- (0)	10 (11)
348	Hesperochloa kingii	- (0)	- (0)	3 (1)	1 (3)	- (0)	3 (1)	3 (3)
321	Juncus drummondii	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
323	Koeleria cristata	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
325	Luzula hitchcockii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
326	Luzula parviflora	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
349	Melica bulbosa	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
329	Oryzopsis asperifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
331	Poa nervosa	7 (6)	7 (3)	6 (1)	6 (6)	9 (3)	3 (15)	7 (1)
330	Stipa occidentalis	- (0)	10 (1)	7 (1)	- (0)	1 (1)	- (0)	- (0)

*Code to constancy values: + = 0- 5% 2 = 15-25% 4 = 35-45% 6 = 55-65% 8 = 75-85% 10 = 95-100%
1 = 5-15% 3 = 25-35% 5 = 45-55% 7 = 65-75% 9 = 85-95%

(con.)

APPENDIX C-1 (con.)

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PINUS ALBICAULIS VASC n= 9	CAGE n= 3	JUCO SHCA n= 3	JUCO JUCO n=15	CARO PICO n=17	CARO CARO n= 3	FEID n= 3
	FORBS							
401	Achillea millefolium	2 (1)	10 (3)	7 (1)	3 (1)	3 (1)	3 (1)	7 (1)
402	Actaea rubra	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
565	Aconitum columbianum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
404	Allium cernuum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
409	Antennaria anaphaloides	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
414	Antennaria microphylla	2 (2)	7 (2)	7 (1)	6 (0)	8 (1)	3 (1)	10 (1)
573	Antennaria parvifolia	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
413	Antennaria racemosa	1 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
754	Aquilegia coerulea	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
420	Arenaria macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
421	Arnica cordifolia	7 (3)	7 (15)	10 (13)	8 (2)	5 (1)	7 (3)	7 (1)
422	Arnica latifolia	3 (6)	- (0)	- (0)	1 (3)	- (0)	7 (2)	- (0)
426	Aster conspicuus	1 (3)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
582	Aster engelmannii	3 (2)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
822	Aster glaucodes	- (0)	- (0)	7 (1)	1 (1)	- (0)	- (0)	- (0)
430	Astragalus miser	1 (3)	- (0)	3 (38)	6 (21)	- (0)	7 (1)	7 (19)
817	Balsamorhiza macrophylla	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
431	Balsamorhiza sagittata	- (0)	- (0)	3 (1)	- (0)	- (0)	- (0)	- (0)
843	Balsamorhiza incana	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
769	Caltha leptosepala	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
436	Campanula rotundifolia	- (0)	10 (1)	7 (1)	3 (1)	1 (1)	3 (0)	3 (1)
438	Castilleja miniata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
594	Castilleja rhexifolia	1 (3)	3 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
442	Chimaphila umbellata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
599	Clematis pseudoalpina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
600	Clematis tenuiloba	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
602	Crepis acuminata	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	3 (1)
847	Cymopteris hendersonii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
455	Disporum trachycarpum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
459	Epilobium angustifolium	3 (1)	7 (3)	7 (1)	3 (3)	4 (1)	10 (1)	7 (1)
465	Fragaria vesca	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
466	Fragaria virginiana	1 (1)	3 (1)	3 (3)	- (0)	1 (2)	- (0)	- (0)
616	Frasera speciosa	- (0)	7 (3)	3 (1)	1 (1)	- (0)	- (0)	3 (1)
471	Galium triflorum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
620	Geranium richardsonii	1 (1)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
473	Geranium viscosissimum	- (0)	- (0)	3 (1)	- (0)	1 (1)	- (0)	- (0)
474	Geum triflorum	- (0)	7 (2)	3 (0)	- (0)	1 (0)	- (0)	3 (3)
476	Goodyera oblongifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
481	Heracleum lanatum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
484	Hieracium albiflorum	- (0)	3 (3)	- (0)	- (0)	1 (1)	- (0)	- (0)
486	Hieracium gracile	2 (2)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
756	Ligusticum filicinum	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
639	Linum perenne	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
641	Lupinus argenteus	- (0)	- (0)	10 (1)	1 (8)	4 (4)	- (0)	3 (15)
649	Mitella pentandra	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
502	Mitella stauropetala	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
505	Osmorhiza chilensis	- (0)	- (0)	- (0)	1 (3)	1 (1)	- (0)	- (0)
653	Osmorhiza depauperata	1 (1)	- (0)	7 (1)	1 (1)	1 (1)	- (0)	- (0)
507	Pedicularis bracteosa	2 (8)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
509	Pedicularis racemosa	1 (3)	7 (1)	- (0)	- (0)	- (0)	- (0)	- (0)
513	Penstemon procerus	1 (1)	- (0)	- (0)	- (0)	- (0)	7 (0)	- (0)
669	Potentilla diversifolia	4 (1)	- (0)	- (0)	1 (1)	1 (1)	7 (1)	3 (3)
521	Potentilla flabellifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
670	Potentilla gracilis	- (0)	7 (2)	3 (1)	1 (1)	1 (1)	- (0)	- (0)
702	Potentilla ovina	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
526	Pyrola asarifolia	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
529	Pyrola secunda	1 (1)	- (0)	3 (0)	3 (2)	2 (0)	- (0)	- (0)
676	Saxifraga arguta	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
840	Senecio lugens	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
681	Senecio streptanthifolius	- (0)	3 (1)	- (0)	2 (1)	1 (1)	- (0)	3 (1)
539	Senecio triangularis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
541	Silene menziesii	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
542	Smilacina racemosa	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
543	Smilacina stellata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
684	Solidago multiradiata	2 (1)	10 (11)	7 (1)	5 (1)	4 (1)	10 (1)	7 (1)
546	Streptopus amplexifolius	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
714	Thalictrum fendleri	1 (37)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
547	Thalictrum occidentale	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
690	Trollius laxus	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
550	Valeriana dioica and occidentalis	- (0)	7 (9)	- (0)	- (0)	- (0)	- (0)	- (0)
554	Viola adunca	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
555	Viola canadensis	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
693	Viola nuttallii	- (0)	- (0)	- (0)	- (0)	1 (1)	- (0)	- (0)
557	Viola orbiculata	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
694	Viola purpurea	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
558	Xerophyllum tenax	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)

APPENDIX C-2. PRESENCE LIST: NUMBERS OF SAMPLE

(see pocket inside back cover)

APPENDIX D-1. SUBSTRATE FEATURES OF EASTERN IDAHO-WESTERN WYOMING HABITAT TYPES AND PHASES

Series	PINUS FLEXILIS				PSEUDOTSUGA MENZIESII																	
Habitat type	HEKI	FEID	CELE	JUCO	SYOR	ARCO	ARCO	CELE	JUCO	BERE	BERE	BERE	CARU	CARU	SPBE	SPBE	OSCH	SYAL	VAGL	ACGL	PHMA	PHMA
Phase		FEID				ARCO	ASMI			SYOR	JUCO	BERE	PAMY	CARU	CARU	SPBE		SYAL	VAGL	PAMY	PAMY	PSME
No. of samples	n=16	n=1	n=3	n=5	n=11	n=12	n=3	n=3	n=17	n=3	n=4	n=7	n=7	n=7	n=2	n=2	n=7	n=9	n=1	n=10	n=4	n=3
COARSE FRAGMENT TYPES (percent of samples)																						
SEDIMENTARY																						
Calcareous	38	.	.	40	27	42	.	33	41	67	75	43	43	14	.	50	.	22	.	30	50	33
Sandstone	6	100	.	.	18	8	.	67	29	.	25	14	29	43	.	50	44	45	.	40	25	.
Miscellaneous	.	.	.	.	.	8	33	.	12	33	.	29	14	29	.	.	28	11	.	10	25	.
METAMORPHIC																						
Quartzite	.	.	.	.	.	.	.	.	6	.	.	.	.	.	50	.	28	.	.	10	.	.
Gneiss & Schist	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
IGNEOUS																						
Basalt & Andesite	19	.	.	20	.	.	.	.	.	.	.	.	.	.	50	.	.	11	100	10	.	67
Dacite, Trachyte & Latite	.	.	.	.	.	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.	.
Rhyolite	6	.	.	.	.	8	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.
Other volcanics	6	.	.	.	.	.	33	.	6	.	.	.	.	.	.	.	.	11	.	.	.	.
Quartz monzonite & Granite	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Granitics (undifferentiated)	.	.	.	20	54	17	33	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
MIXED	25	.	.	20	.	8	.	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.
SUBSTRATE CHARACTERISTICS																						
EXPOSED ROCK (mean %)	5.1	0.9	19.7	6.6	9.7	1.9	10.4	5.1	6.0	0.8	9.0	1.9	0.5	0.8	.	.	0.2	1.3	.	0.9	2.3	.
EXPOSED SOIL (mean %)	4.3	0.5	4.2	0.4	0.9	0.6	0.7	2.4	0.3	1.6	0.5	1.1	1.3	0.4	.	.	1.4	0.3	.	0.5	1.5	.
LITTER DEPTH (mean cm)	2.6	1.0	3.3	3.8	2.8	2.8	2.7	2.5	3.4	1.4	3.0	4.6	2.6	4.1	.	.	4.1	4.5	.	4.5	5.7	.
REACTION (mean pH)	7.0	.	.	6.3	6.4	6.5	6.8	7.2	6.6	.	6.6	6.5	5.6	6.4	.	.	6.0	6.7	.	6.6	38.0	.
GRAVEL CONTENT (mean %)	33.7	.	.	10.1	23.3	17.0	29.3	41.0	22.0	.	20.0	18.7	25.1	18.1	.	.	13.8	25.1	.	14.2	7.0	.

(con.)

APPENDIX D-1 (con.)

Series	PICEA ENGELMANNII										PINUS ALBICAULIS						
Habitat type	HYRE	ARCO	RIMO	JUCO	VASC	LIBO	GATR	CADI	CALE	EQAR	VASC	CAGE	JUCO	JUCO	CARO	CARO	FEID
Phase													SHCA	JUCO	PICO	CARO	
No. of Samples	n=11	n=15	n=4	n=21	n=7	n=2	n=5	n=1	n=8	n=7	n=2	n=0	n=6	n=14	n=12	n=2	n=3
COARSE FRAGMENT TYPES (percent of samples)																	
SEDIMENTARY																	
Calcareous	9	20	50	33	.	.	20	.	.	.	.	.	.	.	.	.	.
Sandstone	.	.	.	5	14	.	20	.	.	.	.	.	17	21	17	.	.
Miscellaneous	.	13	25	14	.	50	40	.	.	.	.	.	17	.	.	.	.
METAMORPHIC																	
Quartzite	.	7	.	.	14	.	20	.	12	.	.	.	.	.	8	.	.
Gneiss & Schist	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
IGNEOUS																	
Basalt & Andesite	9	7	.	9	.	50	.	.	.	.	.	.	33	7	17	.	.
Dacite, Trachyte & Latite	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhyolite	18	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	33
Other Volcanics	45	33	.	14	.	.	.	.	.	.	.	.	.	7	.	.	.
Quartz monzonite & Granite	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	33
Granitics (undifferentiated)	18	7	25	5	43	.	.	100	63	.	50	.	17	64	58	50	.
Miscellaneous	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.
MIXED	.	13	.	9	29	.	.	.	25	.	50	.	17	.	.	50	33
SUBSTRATE CHARACTERISTICS																	
EXPOSED ROCK (mean %)	4.4	0.4	1.8	0.7	4.3	0.5	0.1	0.5	0.2	0.0	.	.	4.5	5.8	4.7	1.0	0.8
EXPOSED SOIL (mean %)	0.5	0.3	0.2	0.4	0.9	0.3	0.1	0.1	0.1	0.1	.	.	0.4	1.9	1.2	0.3	0.5
LITTER DEPTH (mean cm)	5.3	7.2	6.0	4.2	3.7	5.5	12.2	15.5	11.0	13.7	.	.	1.8	3.1	3.4	5.2	2.9
REACTION (mean pH)	6.1	5.8	6.2	6.4	5.2	.	7.1	.	5.7	7.1	.	.	5.5	5.7	5.4	5.8	6.2
GRAVEL CONTENT (mean %)	35.5	17.8	9.4	25.5	17.8	.	25.3	.	11.0	.	.	.	14.2	21.3	17.0	22.0	31.3

APPENDIX D-1 (con.)

Series	ABIES LASIOCARPA													
Habitat type	CACA	ACRU	PHMA	ACGL	LIBO	LIBO	VAGL	VAGL	VAGL	VASC	VASC	VASC	ARLA	SYAL
Phase	CACA			PAMY	VASC	LIBO	VASC	PAMY	VAGL	CARU	PIAL	VASC		
No. of samples	n=1	n=4	n=4	n=7	n=3	n=7	n=2	n=15	n=0	n=4	n=9	n=34	n=3	n=10
COARSE FRAGMENT TYPES (percent of samples)														
SEDIMENTARY														
Calcareous	.	50	.	29	.	.	.	.	.	.	.	.	.	20
Sandstone	.	25	100	57	100	.	50	60	.	50	22	50	33	50
Miscellaneous	.	25	.	14	.	.	.	7	.	25	.	3	.	20
METAMORPHIC														
Quartzite	100	.	.	.	.	29	.	7	.	25	11	18	33	.
Gneiss & Schist	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.
IGNEOUS														
Basalt & Andesite	.	.	.	.	.	57	.	7	.	.	11	.	33	10
Dacite, Trachyte & Latite	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhyolite	.	.	.	.	.	.	.	7	.	.	.	.	.	.
Other volcanics	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Quartz monzonite & Granite	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Granitics (undifferentiated)	.	.	.	.	.	14	.	7	.	.	45	23	.	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.
MIXED	.	.	.	.	.	.	50	7	.	.	11	6	.	.
SUBSTRATE CHARACTERISTICS														
EXPOSED ROCK (mean %)	.	.05	1.1	0.4	0.	1.1	0.	2.9	.	0.1	4.6	2.1	5.5	0.04
EXPOSED SOIL (mean %)	.	.05	0.2	0.3	0.2	0.5	0.7	0.3	.	0.6	0.3	0.1	0.3	0.2
LITTER DEPTH (mean cm)	.	4.9	4.5	3.8	6.0	6.1	4.2	4.1	.	3.7	3.9	4.0	4.3	4.6
REACTION (mean pH)	.	6.4	6.5	5.7	5.2	6.0	5.3	5.3	.	5.2	4.8	5.1	5.3	6.0
GRAVEL CONTENT (mean %)	.	1.0	16.5	20.6	16.1	15.2	9.7	16.7	.	16.5	32.0	21.0	14.0	16.8

(con.)

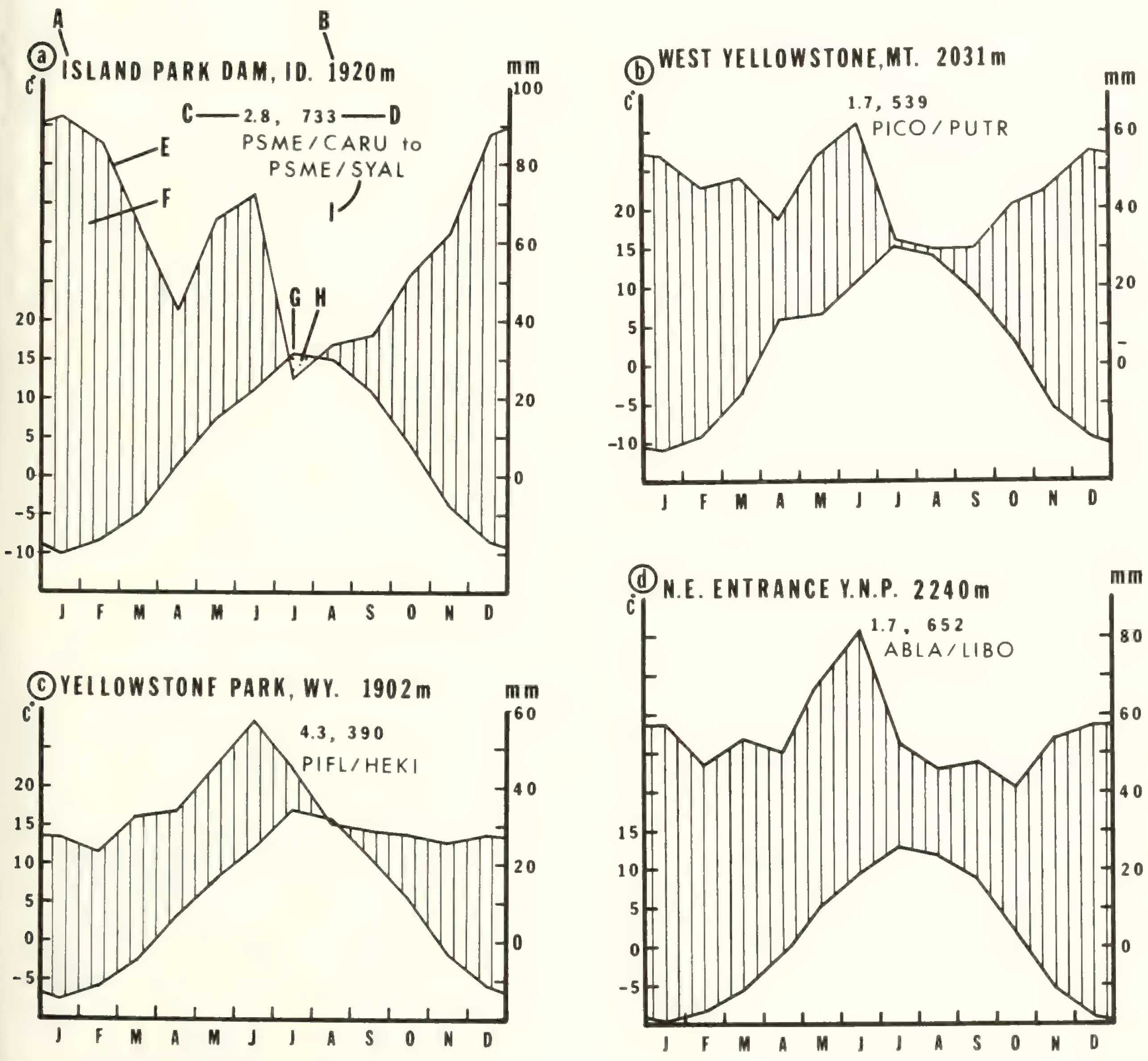
APPENDIX D-1 (con.)

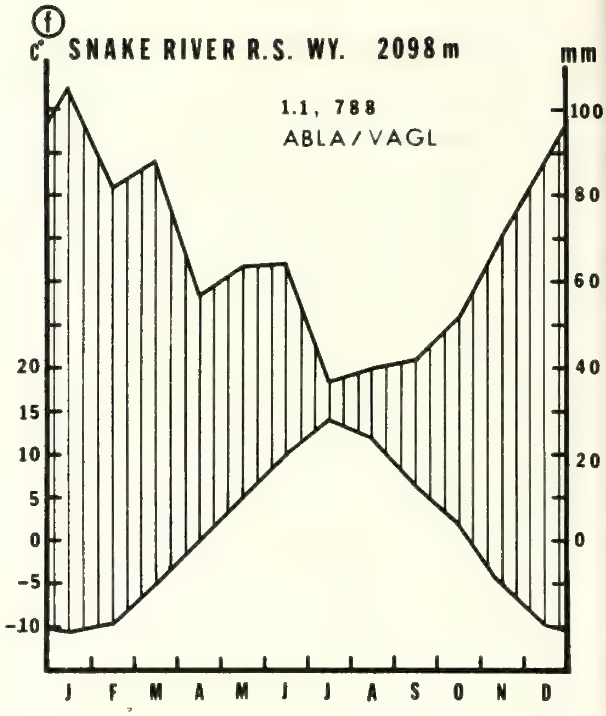
Series	ABIES LASIOCARPA														
Habitat type	THOC	OSCH	OSCH	SPBE	CARU	CARU	BERE	JUCO	RIMO	PERA	ARCO	ARCO	ARCO	ARCO	CARO
Phase		PAMY	OSCH		PAMY	CARU	BERE				PIEN	SHCA	ASMI	ARCO	
No. of samples	n=2	n=4	n=4	n=6	n=3	n=5	n=15	n=10	n=7	n=9	n=4	n=10	n=10	n=22	n=4
COARSE FRAGMENT TYPES (percent of samples)															
SEDIMENTARY															
Calcareous	.	25	25	17	.	.	20	10	.	22	.	.	20	.	.
Sandstone	.	25	.	67	67	80	40	20	71	55	25	40	30	32	25
Miscellaneous	50	.	25	.	.	.	7	10	.	11	.	20	.	5	.
METAMORPHIC															
Quartzite	50	25	25	.	33	.	7	.	14	.	25	.	10	27	50
Gneiss & Schist	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
IGNEOUS															
Basalt & Andesite	.	.	.	.	.	.	13	10	.	.	50	.	20	18	.
Dacite, Trachyte & Latite	.	.	25	.	.	20	.	.	.	.	.	.	.	14	.
Ryolite	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Other volcanics	.	.	.	.	.	.	.	.	.	11	.	.	.	.	.
Quartz monzonite & Granite	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Granitics (undifferentiated)	.	.	.	17	.	.	13	50	14	.	.	30	20	5	.
Miscellaneous	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
MIXED	.	25	.	.	.	.	.	.	.	.	.	10	.	.	25
SUBSTRATE CHARACTERISTICS															
EXPOSED ROCK (mean %)	0.1	0.4	1.2	3.3	3.0	0.4	3.0	1.7	2.0	1.5	0.1	3.4	0.5	1.2	0.4
EXPOSED SOIL (mean %)	0.1	0.2	1.5	1.0	0.5	1.4	0.5	0.8	1.2	0.9	0.1	0.4	0.1	0.9	1.0
LITTER DEPTH (mean cm)	4.2	3.0	4.2	3.0	4.8	3.0	4.2	3.4	5.0	3.4	5.3	3.0	3.9	3.0	1.6
REACTION (mean pH)	6.1	6.5	5.7	6.0	6.0	5.7	5.8	5.9	4.8	5.6	5.6	5.7	5.6	5.2	5.7
GRAVEL CONTENT (mean %)	10.0	16.0	22.3	19.6	18.5	8.4	21.3	16.0	22.0	24.4	12.5	17.0	27.0	28.0	13.5

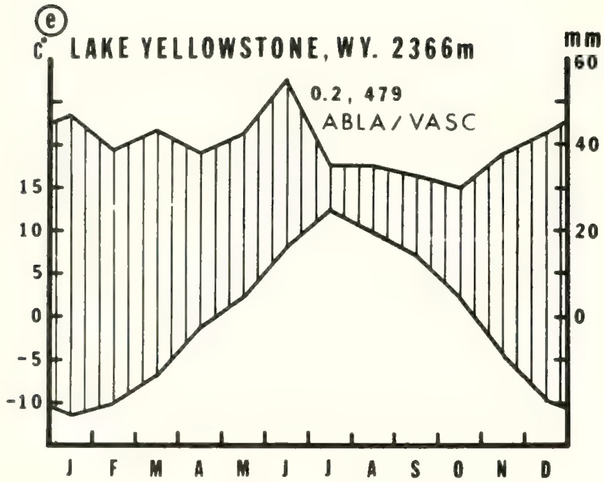
(con.)

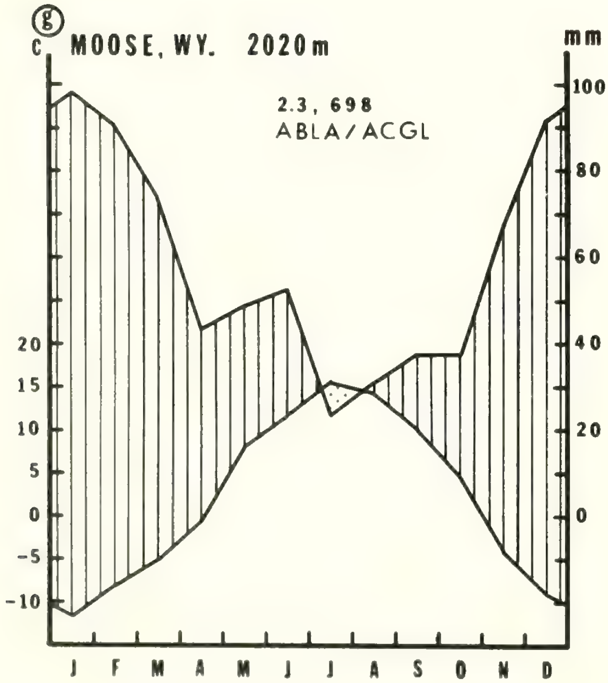
APPENDIX D-2. CLIMATIC PARAMETERS FOR WEATHER STATION WITHIN SELECTED HABITAT TYPES IN EASTERN AND WESTERN WYOMING

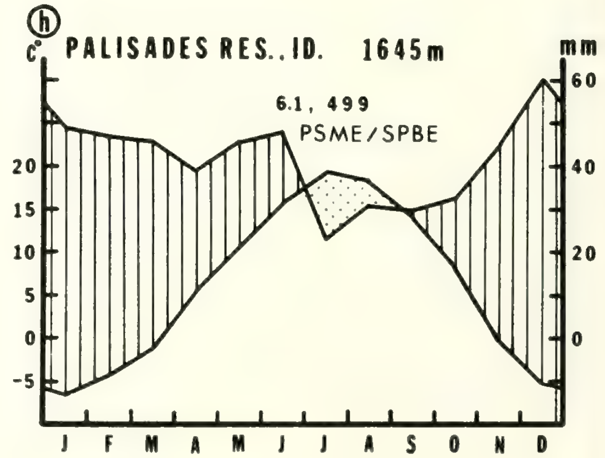
A. Station location
B. Elevation (m)
C. Mean annual temperature (°C)
D. Mean annual precipitation (mm)
E. Pattern of mean monthly precipitation (mm)
F. Hypothetical humid period; precipitation exceeding temperature at scale of 10°C/20mm
G. Pattern of mean monthly temperature (°C)
H. Hypothetical arid period I. Habitat type or community type for station or close proximity thereto



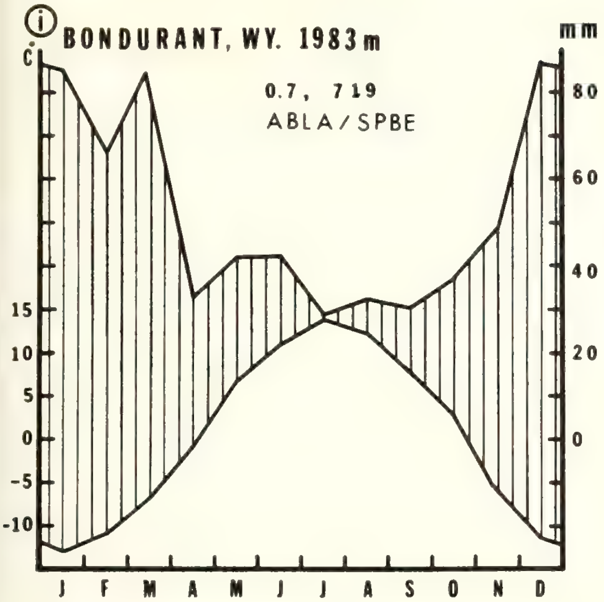

f
C°
SNAKE RIVER R.S. WY. 2098 m
mm
1.1, 788
ABLA / VAGL
100
80
60
40
20
0
20
15
10
5
0
-5
-10
J F M A M J J A S O N D

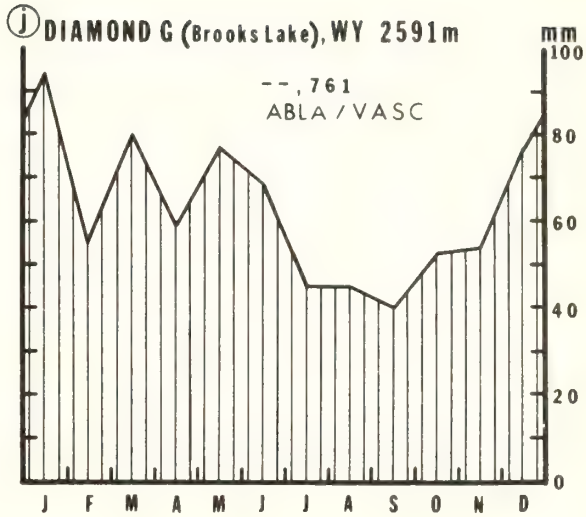

e
C°
LAKE YELLOWSTONE, WY. 2366m
mm
60
0.2, 479
ABLA / VASC
40
20
0
15
10
5
0
-5
-10
J F M A M J J A S O N D

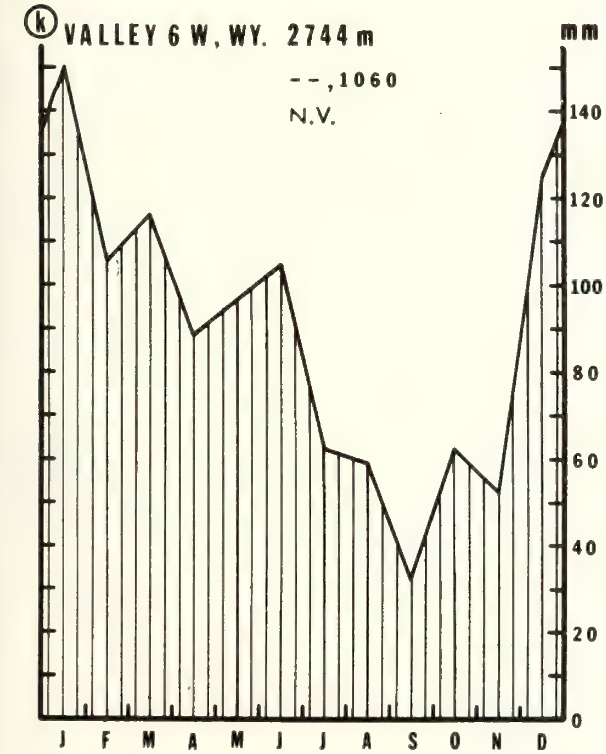

g
C
MOOSE, WY. 2020m
mm
100
2.3, 698
ABLA / ACGL
80
60
40
20
0
20
15
10
5
0
-5
-10
J F M A M J J A S O N D

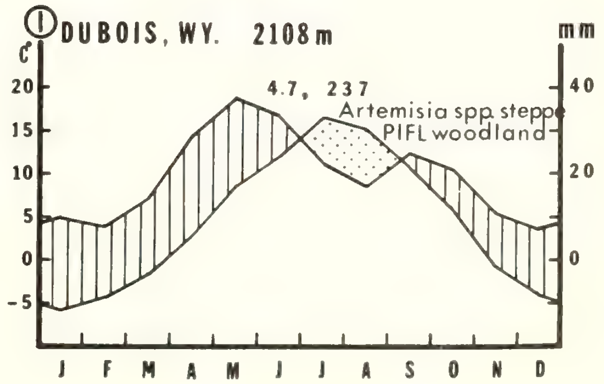

h
C°
PALISADES RES., ID. 1645m
mm
60
6.1, 499
PSME / SPBE
40
20
0
20
15
10
5
0
-5
J F M A M J J A S O N D

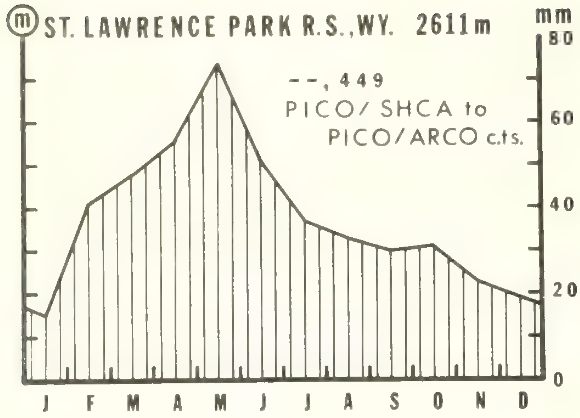
APPENDIX D-2. (con.)

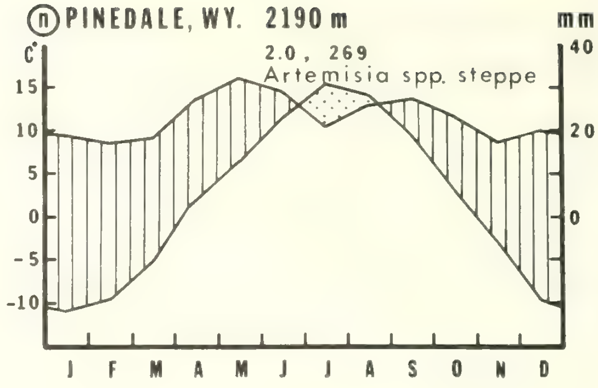


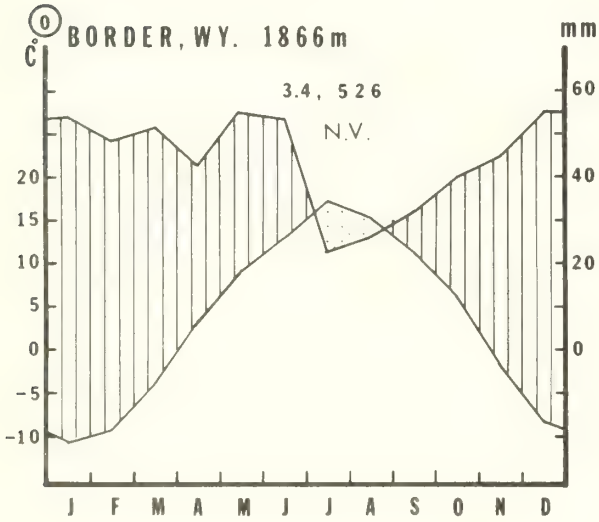


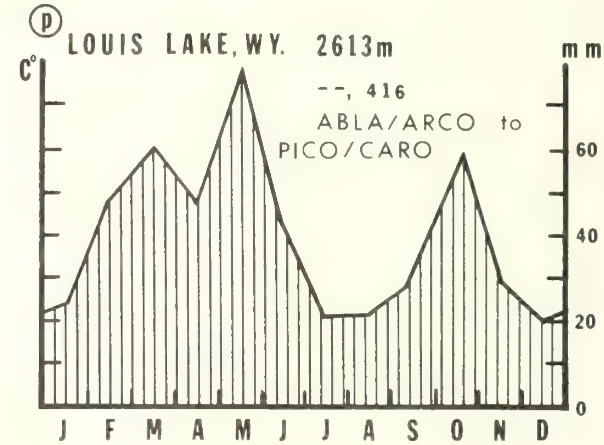


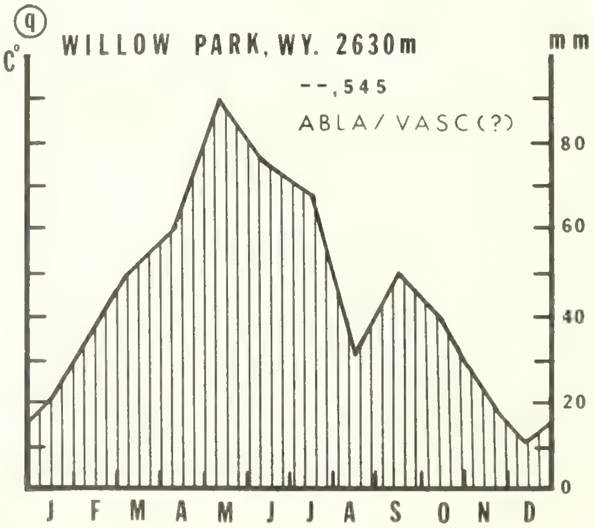



(m) ST. LAWRENCE PARK R.S., WY. 2611m
mm
80
60
40
20
0
--, 449
PICO/SHCA to
PICO/ARCO c.t.s.
J F M A M J J A S O N D


(n) PINEDALE, WY. 2190 m
C°
mm
15
10
5
0
-5
-10
40
20
0
2.0, 269
Artemisia spp. steppe
J F M A M J J A S O N D


(o) BORDER, WY. 1866m
C°
mm
20
15
10
5
0
-5
-10
60
40
20
0
3.4, 526
N.V.
J F M A M J J A S O N D


(p) LOUIS LAKE, WY. 2613m
C°
mm
60
40
20
0
--, 416
ABLA/ARCO to
PICO/CARO
J F M A M J J A S O N D


(q) WILLOW PARK, WY. 2630m
C°
mm
80
60
40
20
0
--, 545
ABLA/VASC(?)
J F M A M J J A S O N D

APPENDIX E-1. MEAN BASAL AREAS AND 50-YEAR SITE INDEXES FOR EASTERN IDAHO-WESTERN WYOMING BY HABITAT TYPE.

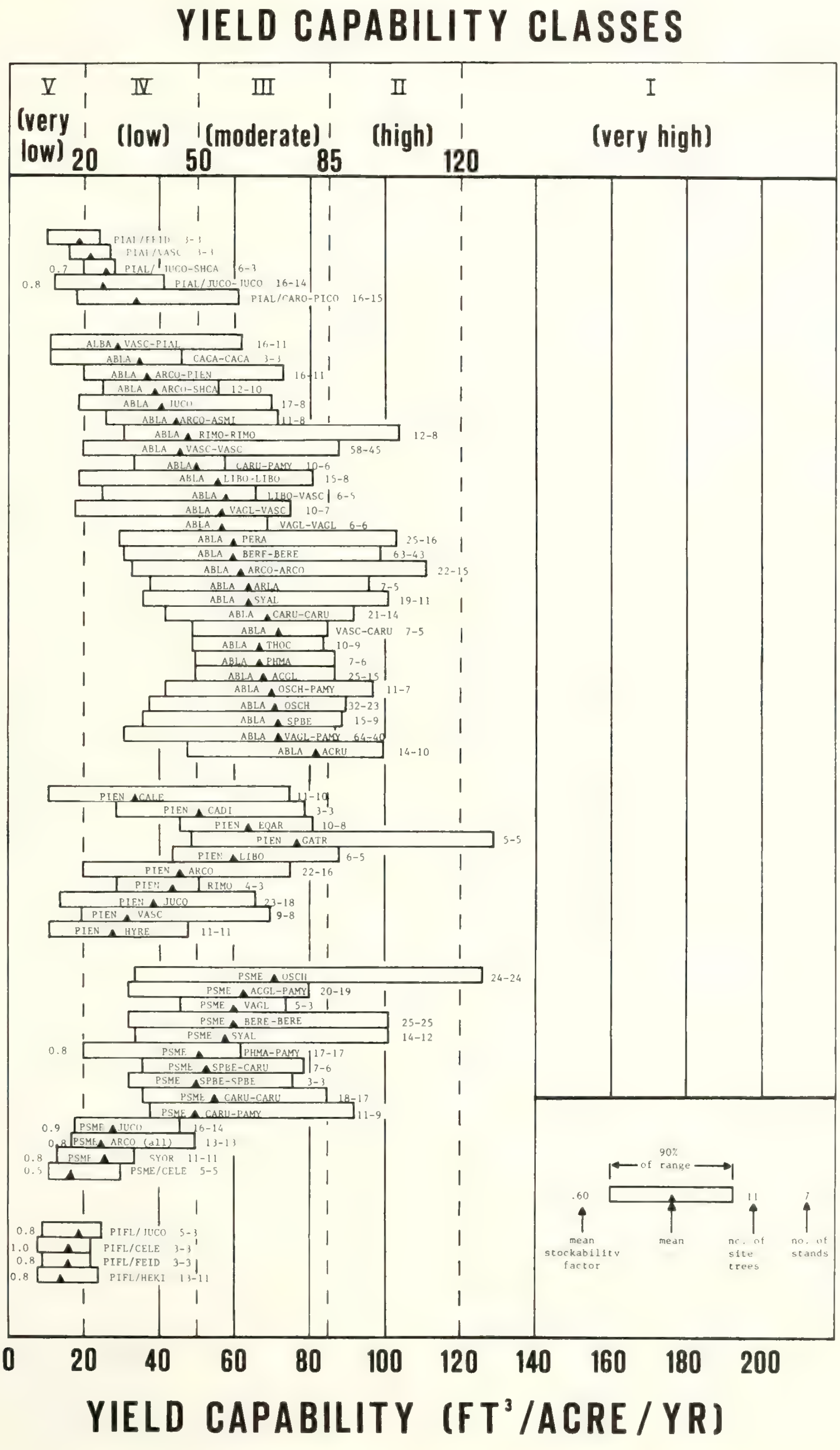
Means are shown where n = 3 or more; confidence limits (95 percent) for estimating the mean are given where n = 5 or more

Habitat type, phase	Basal area (ft^2/acre)	Site index by species				
		PSME	PICO	PIEN	ABLA	PIAL/PIFL
PIFL/HEKI	121 ± 25	25 ±	10 ±	.	.	.
PIFL/FEID	133 ± ?	.	.	.	.	.
PIFL/CELE	136 ± ?	16 ± ?	.	.	.	.
PIFL/JUCO	147 ± 71	.	.	.	.	.
PSME/SYOR	130 ± 30	32 ± 6	.	.	.	.
PSME/ARCO, ARCO	158 ± 20	32 ± 8	.	.	.	.
PSME/ARCO, ASMI	106 ± ?	30 ± ?	.	.	.	.
PSME/CELE	91 ± 45	36 ± 13	.	.	.	.
PSME/JUCO	160 ± 22	28 ± 5	37 ± ?	.	.	.
PSME/BERE, SYOR	119 ± ?	45 ± ?	.	.	.	.
PSME/BERE, JUCO	.	34 ± ?	.	.	.	.
PSME/BERE, BERE	172 ± 27	51 ± 5	.	.	.	.
PSME/CARU, PAMY	114 ± 33	51 ± 9	.	.	.	.
PSME/CARU, CARU	190 ± 22	47 ± 5	.	.	.	.
PSME/SPBE, CARU	201 ± 41	48 ± 11	.	.	.	.
PSME/SPBE, SPBE	208 ± 55	44 ± ?	.	.	.	.
PSME/OSCH	164 ± 32	56 ± 5	.	.	.	.
PSME/SYAL, SYAL	167 ± 25	50 ± 9	.	.	.	.
PSME/VAGL, VAGL	145 ± ?	51 ± ?	49 ± ?	.	.	.
PSME/ACGL, PAMY	194 ± 40	53 ± 5	.	.	.	.
PSME/PHMA, PAMY	168 ± 30	48 ± 4	.	.	.	.
PSME/PHMA, PSME	198 ± ?	.	.	.	.	.
PIEN/HYRE	233 ± 8	.	.	27 ± 8	.	.
PIEN/ARCO	210 ± 19	33 ± ?	31 ± ?	39 ± 8	.	.
PIEN/RIMO	205 ± ?	.	.	36 ± ?	.	.
PIEN/JUCO	159 ± 19	23 ± 8	37 ± ?	35 ± 7	.	.
PIEN/VASC	229 ± 62	.	37 ± ?	35 ± 7	.	.
PIEN/LIBO	202 ± 55	.	41 ± ?	52 ± ?	.	.
PIEN/GATR	285 ± 133	.	.	56 ± 20	.	.
PIEN/CADI	241 ± ?	.	.	42 ± ?	.	.
PIEN/CALE	195 ± 27	.	.	32 ± 8	.	.
PIEN/EQAR	241 ± 78	.	.	51 ± 7	35 ± ?	.

APPENDIX E-1 (con.)

Habitat type, phase	Basal area (ft²/acre)	Site index by species				
		PSME	PICO	PIEN	ABLA	PIAL/PIFL
ABLA/CACA, CACA	182 ± ?	.	.	.	.	.
ABLA/ACRU	209 ± 33	.	68 ± ?	50 ± 11	61 ± ?	.
ABLA/PHMA	191 ± 29	43 ± 19	.	.	.	.
ABLA/ACGL, PAMY	156 ± 7	54 ± 7	46 ± 11	53 ± ?	55 ± ?	
ABLA/LIBO, VASC	189 ± 74	.	45 ± ?	41 ± ?	.	.
ABLA/LIBO, LIBO	221 ± 41	41 ± ?	41 ± ?	40 ± 11	37 ± ?	.
ABLA/VAGL, VASC	202 ± 67	.	.	43 ± 15	.	.
ABLA/VAGL, PAMY	194 ± 21	44 ± 5	45 ± 6	48 ± 4	42 ± 9	.
ABLA/VAGL, VAGL	228 ± 82	51 ± ?	50 ± ?	55 ± ?	.	.
ABLA/VASC, CARU	111 ± 39	.	52 ± 8	.	.	.
ABLA/VASC, PIAL	223 ± 36	.	28 ± ?	37 ± 6	25 ± 4	.
ABLA/VASC, VASC	209 ± 27	.	37 ± 5	40 ± 5	33 ± 4	.
ABLA/ARLA	229 ± 60	37 ± ?	42 ± ?	45 ± 8	28 ± 8	.
ABLA/SYAL	136 ± 24	48 ± ?	50 ± 9	63 ± ?	54 ± 9	.
ABLA/THOC	261 ± 44	.	49 ± ?	51 ± 4	.	.
ABLA/OSCH, PAMY	250 ± 60	49 ± ?	53 ± ?	.	53 ± ?	.
ABLA/OSCH, OSCH	204 ± 30	47 ± 4	50 ± 8	.	46 ± 9	.
ABLA/SPBE	175 ± 27	50 ± ?	48 ± 8	52 ± ?	55 ± 16	.
ABLA/CARU, PAMY	246 ± 183	44 ± 7	46 ± ?	.	44 ± ?	.
ABLA/CARU, CARU	155 ± 27	57 ± ?	51 ± 7	.	50 ± 11	.
ABLA/BERE, BERE	206 ± 23	47 ± 4	46 ± 5	58 ± 7	46 ± 6	.
ABLA/JUCO	165 ± 44	35 ± ?	39 ± 15	28 ± ?	40 ± 15	.
ABLA/RIMO, RIMO	.	.	.	.	.	
ABLA/PERA	184 ± 34	37 ± 10	45 ± 9	47 ± 7	40 ± 13	.
ABLA/ARCO, PIEN	208 ± 53	.	36 ± ?	39 ± 10	36 ± 10	.
ABLA/ARCO, SHCA	134 ± 31	41 ± ?	37 ± 7	.	33 ± ?	.
ABLA/ARCO, ASMI	199 ± 41	.	36 ± 10	45 ± ?	40 ± ?	.
ABLA/ARCO, ARCO	238 ± 47	.	49 ± 13	54 ± ?	46 ± 8	.
ABLA/CARO	.	.	.	.	.	
PIAL/VASC	240 ± 73	.	21 ± ?	.	.	.
PIAL/CAGE	196 ± ?	.	.	.	.	.
PIAL/JUCO, SHCA	118 ± ?	.	36 ± 4	.	.	.
PIAL/JUCO, JUCO	143 ± 33	.	28 ± 5	.	.	.
PIAL/CARO, PICO	171 ± 29	.	30 ± 5	.	.	.
PIAL/CARO, CARO	253 ± ?	.	.	.	.	.
PIAL/FEID	150 ± ?	.	.	.	.	15 ± ?

APPENDIX E-2. ESTIMATED YIELD CAPABILITY OF EASTERN IDAHO-WESTERN WYOMING HABITAT TYPES BASED ON SITE INDEX DATA AND STOCKABILITY FACTORS



APPENDIX F. EASTERN IDAHO-WESTERN WYOMING HABITAT TYPE FIELD FORM (FOR 3 PLOTS)

NAME

(CODE DESCRIPTION)

TOPOGRAPHY:	HORIZONTAL CONFIGURATION:	CANOPY COVERAGE CLASS:	
1-Ridge	1-Convex (dry)	0=Absent	3=25 to 50%
2-Upper slope	2-Straight	T=Rare to 1%	4=50 to 75%
3-Mid slope	3-Concave (wet)	1=1 to 5%	5=75 to 95%
4-Lower slope	4-undulating	2=5 to 25%	6=95 to 100%
5-Bench or flat			
6-Stream bottom			

NOTE: Rate trees (>4" dbh) and regen, (0-4" dbh) separately (e.g., 4/2)

DATE			
Plot No.			
Location			
T.R. S.			
Elevation			
Aspect			
Slope			
Topography			
Configuration			

	Scientific Name	Abbrev.	Common Name	Canopy Coverage Class		
TREES						
1.	Abies lasiocarpa	ABLA	subalpine fir	/	/	/
2.	Picea engelmannii	PIEN	Engelmann spruce	/	/	/
3.	Picea glauca	PIGL	white spruce	/	/	/
4.	Picea pungens	PIPU	blue spruce	/	/	/
5.	Pinus albicaulis	PIAL	whitebark pine	/	/	/
6.	Pinus contorta	PICO	lodgepole pine	/	/	/
7.	Pinus flexilis	PIFL	limber pine	/	/	/
8.	Pseudotsuga menziesii	PSME	Douglas-fir	/	/	/
9.	Populus tremuloides	POTR	quaking aspen	/	/	/
SHRUBS AND SUBSHRUBS						
1.	Acer glabrum	ACGL	mountain maple			
2.	Berberis repens	BERE	creeping Oregon grape			
3.	Cercocarpus ledifolius	CELE	curleaf mountain-mahogany			
4.	Juniperus communis	JUCO	common juniper			
5.	Ledum glandulosum	LEGL	Labrador tea			
6.	Linnaea borealis	LIBO	twinflower			
7.	Menziesia ferruginea	MEFE	menziesia			
8.	Pachistima myrsinites	PAMY	pachistima			
9.	Physocarpus malvaceus	PHMA	ninebark			
10.	Physocarpus monogynus	PHMO	mountain ninebark			
11.	Prunus virginiana	PRVI	chokecherry			
12.	Ribes cereum	RICE	squaw current			
13.	Ribes montigenum	RIMO	mountain gooseberry			
14.	Shepherdia canadensis	SHCA	russett buffalo-berry			
15.	Sorbus scopulina	SOSC	mountain ash			
16.	Spiraea betulifolia	SPBE	white spirea			
17.	Symphoricarpos albus	SYAL	common snowberry			
18.	Symphoricarpos oreophilus	SYOR	mountain snowberry			
19.	Vaccinium caespitosum	VACA	dwarf huckleberry			
20.	Vaccinium globulare (+ membranaceum)	VAGL	blue huckleberry			
21.	Vaccinium scoparium (+ myrtillus)	VASC	grouse whortleberry			
GRAMINOIDS						
1.	Agropyron spicatum	AGSP	bluebunch wheatgrass			
2.	Calamagrostis canadensis	CACA	bluejoint			
3.	Calamagrostis rubescens	CARU	pinegrass			
4.	Carex disperma	CADI	soft-leaved sedge			
5.	Carex geyeri	CAGE	elk sedge			
6.	Carex rossii	CARO	Ross sedge			
7.	Festuca idahoensis	FEID	Idaho fescue			
8.	Hesperochloa kingii	HEKI	spike fescue			
9.	Luzula hitchcockii	LUHI	smooth woodrush			
FORBS						
1.	Actaea rubra	ACRU	baneberry			
2.	Aconitum columbianum	ACCO	monkshood			
3.	Arnica cordifolia	ARCO	heartleaf arnica			
4.	Arnica latifolia	ARLA	mountain arnica			
5.	Astragalus miser	ASMI	weedy milkvetch			
6.	Caltha leptosepala	CALE	elkslip marshmarigold			
7.	Equisetum arvensis	EQAR	common horsetail			
8.	Galium triflorum	GATR	sweetscented bedstraw			
9.	Osmorhiza chilensis (+ depauperata)	OSCH	mountain sweetroot			
10.	Pedicularis racemosa	PERA	pedicularis			
11.	Senecio triangularis	SETR	arrowleaf groundsel			
12.	Streptopus amplexifolius	STAM	twisted stalk			
13.	Thalictrum occidentale	THOC	western meadowrue			
14.	Trollius laxus	TRLA	globe flower			
15.	Xerophyllum tenax	XETE	beargrass			
			SERIES			
			HABITAT TYPE			
			PHASE			

APPENDIX G. Glossary

The following terms are defined as used in this report. The definitions should minimize misunderstanding resulting from the fact that definitions may vary among specialists. Primary references include Hanson (1962), Ford-Robertson (1971), and Daubenmire (1968).

Abundant. When relating to plant coverage in the habitat type key, any species having a canopy coverage of 25 percent or more in a stand.

Accidental. A species that is found rarely or at most occasionally as scattered individuals in a given habitat type.

Association. A climax plant community; all climax stands consisting of essentially the same vegetational layers.

Basal area. The area of the cross-section of a tree trunk at 4.5 feet above the ground, usually expressed as the sum of tree basal areas in square feet per acre.

Bench, benchland. An area having flat or gently-sloping terrain (less than 15 percent slope), applied usually to the higher ground in a river valley.

Browse. (noun) Shrubby forage utilized especially by large animals. (verb) To eat shrubby forage.

Canopy coverage. The area covered by the gross outline of an individual plant's foliage, or collectively covered by all individuals of a species within a stand or sample plot. Canopy coverage is expressed as a percentage of the total area in the plot, or as a canopy coverage class (for example, class #1 = 1 to 5 percent coverage).

Classification. The orderly arrangement of objects according to their differences and similarities.

Climax community. The culminating stage in plant succession for a given environment that develops and perpetuates itself in the absence of disturbance.

Climax species. A species that is self-regenerating in the absence of disturbance with no evidence of replacement by other species.

Climax, types of ... in relation to environment (polyclimax concept).

Climatic climax. The climax vegetation that develops on "normal" soils (well-drained medium-textured) and gently sloping topography.

Edaphic climax. A variation in vegetation from the climatic climax caused by soils that differ from those of the climatic climax.

Topographic climax. A variation in vegetation from the climatic climax caused by topography that markedly influences microclimate.

Topo-edaphic climax. A variation in vegetation from the climatic climax caused by the combination of topographic and edaphic effects. (Example: *Pseudotsuga menziesii* stands occupying rocky north-slopes surrounded by nonforest habitat types.)

Common. When relating to plant coverage in the habitat type key, any species having a canopy coverage of 1 percent or more in a stand.

Community (plant community). An assembly of plants living together, denotes no particular ecological status. The basic unit of vegetation.

Community type. A classified plant community distinguished by various criteria, may be seral or climax.

Constancy. The percentage of stands in a habitat type that contain a given species. (Appendix C-1 uses "constancy classes" — "1" = 5 to 15 percent, "2" = 15 to 25 percent, etc.)

Cover type. A classified plant community distinguished by the existing dominant or codominant plant canopies.

Cryptogam. A collective term for a group of nonvascular plants, mainly mosses, lichens, liverworts and hornworts.

d.b.h. (diameter at breast height). Tree-trunk diameter measured at 4.5 feet (1.4 m) above the ground.

Depauperate. Describing an unusually sparse coverage of undergrowth vegetation. This condition often develops beneath a dense forest canopy, especially on sites having a deep layer of duff.

Disjunct. A segment of a population that is separated geographically from the main population.

Dominant. The species having the greatest canopy coverage; may refer to only the vegetational layer in which that species occurs or may refer to that layer plus others.

Ecologic amplitude. The range of environments occupied by a species, union, association, or series.

Ecosystem. Any community of organisms along with its environment, forming an interacting system.

Ecotone. The boundary or transition zone between adjacent plant communities, often delineating different habitat types and sometimes expressed as a hybrid stand.

Ecotype. A genetic race of a species adapted to a particular habitat.

Edaphic. Refers to soil.

Endemic. Indigenous to a particular local geographic area.

Forb. An herbaceous, usually broadleaved plant that is not a graminoid.

Forest cover type. A classified tree layer distinguished by the existing dominant or codominant trees.

Frequency. The percentage of quadrats (tiny plots) in a single sample stand that contain a given species, or more generally the degree of uniformity with which individuals of a species are distributed in a stand.

Graminoid. All grasses (Gramineae) and grasslike plants, including sedges (*Carex*) and rushes (*Juncus*).

Habitat type. An aggregation of all land areas potentially capable of producing similar plant communities at climax.

Hybrid stand. A stand which displays the differential characteristics of more than one habitat type, often indicating an ecotone.

Identification. The placing of an individual object into its proper class according to some preestablished classification.

Indicator plant. A plant whose presence or abundance indicates certain environmental conditions—generally used in the classification of a habitat type or phase.

Mosaic. The pattern of different entities abutting each other.

'Natural' classification. A stratification derived from the clustering within a system according to all the traits of its individuals— generally applied to classifications that are based on natural relationships and serve a large number of purposes; however, no classification is truly natural since all are man made.

Phase. A subdivision of an association and a habitat type representing a characteristic variation in climax vegetation and environmental conditions, respectively.

Phenotype. A group of individuals distinguishable on the basis of morphological characteristics—in contrast to a "genotype" which is defined on the basis of genetic similarities.

Physiography. The study of the genesis and evolution of land forms.

Poorly represented. When relating to plant coverage in the habitat type key, any species that is absent or has a canopy coverage of less than 5 percent.

Riparian. Vegetation bordering watercourses, lakes, or swamps.

Scarce. When relating to plant coverage in the habitat type key, any species that is absent or has a canopy coverage of less than 1 percent.

Scree. Any slope covered with loose rock fragments. This includes accumulation of rock at the base of a cliff (talus) as well as loose material lying on slopes without cliffs.

Seral. A species or community that is replaced by another species or community as succession progresses.

Series. In forest site classification, a group of habitat types having the same climax dominant tree species. For example the *Pinus flexilis* series contains the *PIFL/HEKI, PIFL/FEID, PIFL/CELE*, and *PIFL/JUCO* h.t.'s.

Site index. An index of timberland productivity based upon the height of dominant or codominant trees at a certain reference age (usually 50 or 100 years).

Stand. An existing plant community that is relatively uniform in composition, structure, and habitat conditions; thus it may serve as a local example of a community type on a habitat type.

Stockability factor. An estimate of the stocking potential on a given site; for example a factor of 0.8 indicates that the site is capable of supporting only about 80 percent of "normal" stocking as indicated in yield tables.

Stocking. A general term for the number of trees (considering their size class) per acre.

Succession. The progressive changes in plant communities toward climax, with qualification, may refer to progressive changes in a direction other than climax.

Tolerance. The performance of a species in regard to particular environmental factors such as light or moisture, the extremes of which constitute its range of tolerance.

Union. A classified vegetational layer of an association that generally reappears in other associations, consisting of one or more species considered to have similar ecologic amplitudes within a given geographic area.

Well represented. When referring to plant coverage in the habitat type key, any species having a canopy coverage of greater than 5 percent.

Yield capability. The maximum mean annual increment attainable in a fully stocked natural stand, expressed in cubic feet per acre per year. (See a forest mensuration textbook for the distinction between "mean annual increment" and "periodic annual increment"; growth in a specific year, or period of years, is termed the latter.)

Zone. An area of land distinguished by the dominant climatic climax vegetation.

Steele, Robert; Cooper, Stephen V.; Ondov, David M.; Roberts, David W.; Pfister, Robert D. Forest habitat types of eastern Idaho-western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 1983. 122 p.

A land-classification system based upon potential natural vegetation is presented for the forests of central Idaho. It is based on reconnaissance sampling of about 980 stands. A hierarchical taxonomic classification of forest sites was developed using the habitat type concept. A total of six climax series, 58 habitat types, and 24 additional phases of habitat types are defined and described. A diagnostic key is provided for field identification of the types based on indicator species used in development of the classification.

KEYWORDS: forest vegetation, Idaho, habitat types, plant communities, forest ecology, forest management, classification, Wyoming

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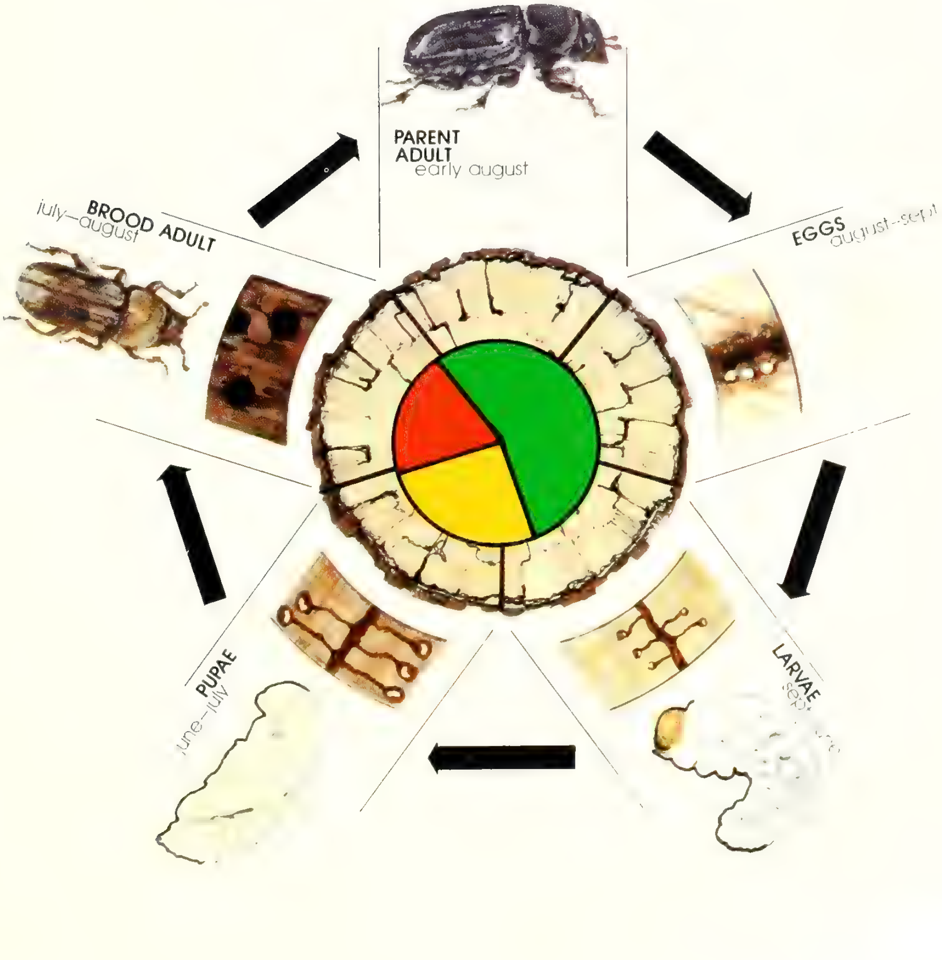
**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-145

July 1983

Mountain Pine Beetle Dynamics in Lodgepole Pine Forests Part II: Population Dynamics

Gene D. Amman and Walter E. Cole



A

B

C

D

Figure 2.—Life stages of the mountain pine beetle: A. egg; B. larva; C. pupa; D. adult. (Photo A courtsey of Pacific Forest Research Centre, Canadian Forestry Service, Victoria, B.C.)

Cover photo: Generalized drawing of mountain pine beetle life cycle. Circle in the center shows color changes in tree foliage following infestation by beetles.

THE AUTHORS

NE D. AMMAN is a principal entomologist on the In-
nountain Station's Population Dynamics of the Moun-
i Pine Beetle Research Work Unit, an assignment that
jan in 1966. Previously, he was research entomologist
h the Southeastern Forest Experiment Station in Ashe-
e, N.C., doing biological control and ecological research
the balsam woolly aphid. He began his career with the
cky Mountain Forest and Range Experiment Station in
t Collins, Colo., as research assistant sampling popula-
ns and mortality factors of mountain pine beetle and
uce beetle. He received a B.S. degree in biological
ence and an M.S. degree in zoology from Colorado State
versity, and a Ph.D. degree in forestry from the Uni-
sity of Michigan.

LTER E. COLE is project leader of the Intermountain
tion's Population Dynamics of the Mountain Pine
etle Research Work Unit. He started the unit in 1960
l laid the groundwork for research on this beetle. He
o conducted population dynamics research, control, and
vey work on the spruce budworm and pine butterfly in
ithern Idaho. He began his career with Forest Insect In-
tigations, Bureau of Entomology and Plant Quarantine
Berkeley, Calif., and conducted biological research and
veys on the spruce beetle in Colorado. He holds B.S.
l M.S. degrees in entomology from Colorado State Uni-
sity, and a Ph.D. degree in entomology from North
olina State University.

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eriment Station, Flagstaff, Ariz.; and Dr. Molly W.
ck, University of Idaho, Moscow.
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ska, Juneau; Dennis M. Cole, Intermountain Forest and
ige Experiment Station, Bozeman, Mont.; William H.
in, USDA Forest Service, Methods Application Group,
is, Calif.

RESEARCH SUMMARY

Much of this work is original research by the authors. However, published literature on the taxonomy, biology, and population dynamics of the beetle are reviewed primarily as they occur in epidemic beetle populations in lodgepole pine forests. Lodgepole pine tree characteristics such as size and phloem thickness have a strong influence on beetle survival, size, sex ratio, and genotype. Of the many mortality factors acting upon the beetle population alone or in combination, none regulate the population before severe damage occurs to stands of lodgepole pine. These findings demonstrate that the mountain pine beetle is food regulated.

CONTENTS

PREFACE

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is a native bark beetle whose depredations cause various effects upon the lodgepole pine, *Pinus contorta* Douglas var. *latifolia* Engelmann, ecosystem. Historically, the beetle kills millions of trees each year in the United States and Canada. During epidemics, a single National Forest may lose more than a million trees in a single year; for example, 3.6 million lodgepole pines were killed on the Targhee National Forest, Idaho, in 1976 (Klein and others 1979). The mountain pine beetle has killed an estimated average of 2 billion bd.ft. per year since 1895 (Wood 1963). In 1970, volume loss of growing stock to all mortality causes totaled some 613 million ft^3 (17.4 million m^3) within the Rocky Mountain States; this is equivalent to nearly 75 percent of the volume that went into roundwood products. Sawtimber volume losses approximated 208 million ft^3 (5.9 million m^3)—equivalent to almost 50 percent of the roundwood products output from sawtimber (Green and Setzer 1974). The mountain pine beetle in lodgepole and ponderosa pines accounted for about 473.3 million ft^3 (13.4 million m^3) or 77 percent of this timber loss. Similar losses could be expected in the West Coast States. In western Canada, losses of lodgepole pine to the mountain pine beetle were estimated to be 1.3 million ft^3 (36 900 m^3) per year between 1950 and 1970 (Safranyik and others 1975). This impact places the mountain pine beetle as the prime insect agent affecting the lodgepole pine ecosystem. The effects of beetle infestations change the entire lodgepole pine environment and, depending on subsequent occurrence or exclusion of fire, largely determine the nature of successional dynamics—to lodgepole pine renewal in the case of fire, or to succession of more shade-tolerant species in the absence of fire.

Tree mortality in pine stands can occur as scattered individual trees, but more often entire groups of trees are killed. Unchecked, these groups expand with succeeding beetle generations, and eventually large areas may suffer extreme losses of their forest cover. This may or may not be a catastrophic situation, depending on landowner objective. Some landowners, for example, favor grassland over timberland, and a bark beetle outbreak may in fact be no disaster in their eyes. On the other hand, the value of a mountain home may be severely reduced by the death of high-value shade trees, and the owner may view this loss as highly undesirable. From the timber-producer standpoint, the beetle can disrupt management plans and cause an unwelcomed impact on local, regional, and national economies.

This treatise represents much original research by the authors, but also is a review of other published literature about the mountain pine beetle, with particular reference to epidemic infestations. Much research remains to be done in testing and applying management strategies indicated by this research. Also in need of study are the dynamics of mountain pine beetle populations during endemic periods. During periods of low beetle activity, we believe significant "keys" exist that will permit more effective management of stands to prevent population increases.

Our research approach first addressed the recognition and determination of relationships between the insect and its associated environmental factors. These relationships were based on biological functions, and they were studied to determine their biological effect upon the insect. Secondly, quantification of these relationships was based upon measurement units relative to beetle behavior. The host variable was considered an integral unit within the ecosystem.

We intend to lead readers through this maze of interactive relationships to the extent of their interest and existing knowledge. With this in mind, we will have three parts published as separate general technical reports:

I. **Course of an Infestation**—including beetle impact on the lodgepole pine stand, how the beetle "moves through" the stand, expected timber mortality, and management alternatives. (See Intermountain Forest and Range Experiment Station publication General Technical Report INT-89, published in 1980.)

II. **Mountain Pine Beetle Population Dynamics**—including bionomics, analyses of mortality factors, entomological relationships, and the "inner workings" of a mountain pine beetle population. (This current volume.)

III. **Sampling and Modeling of Mountain Pine Beetle Populations**—including methods of sampling and modeling both lodgepole pine and mountain pine beetle populations. (In preparation.)

Mountain Pine Beetle Dynamics in Lodgepole Pine Forests
Part II: Population Dynamics

BIONOMICS

Taxonomy

Hopkins (1902) named *Dendroctonus ponderosae* the "pine destroying beetle of the Black Hills" from specimens collected from ponderosa pine, *Pinus ponderosa* Lawson, in the Black Hills of South Dakota. Three years later, Hopkins (1905) gave more details about *D. ponderosae* and shortened the common name to Black Hills beetle. This beetle was found in Arizona, Colorado, New Mexico, Utah, and Wyoming. Host trees were ponderosa pine; limber pine, *Pinus flexilis* James; white spruce, *Picea glauca* Moench Voss (Hopkins used *P. canadensis*); and Engelmann spruce, *P. engelmanni* Parry. However, Hopkins said the beetle was not destructive to Engelmann spruce.

The mountain pine beetle[1] *Dendroctonus monticolae*, was described by Hopkins (1909). The following were host trees: sugar pine, *Pinus lambertiana* Douglas; western white pine, *P. monticola* Douglas; lodgepole pine, *P. contorta* Douglas; and ponderosa pine. The mountain pine beetle was found in California, Idaho, Montana, Oregon, Washington, and Wyoming. Also, Hopkins (1909) described *Dendroctonus jeffreyi*, the Jeffrey pine beetle, from *Pinus jeffreyi* Greville and Balfour. He listed ponderosa pine as a host.

Blackman[2] thought that *D. monticolae* and *D. ponderosae* constituted a single species that varied according to host, food supply, and region. Blackman's contention was supported by experimental mating of *D. ponderosae* and *D. monticolae*, the progeny of which made successful attacks and produced fertile offspring (Hay 1956).

In a comprehensive treatment of the genus *Dendroctonus*, Wood (1963) combined *monticolae, ponderosae*, and *jeffreyi*. This synonymy was corroborated by studies of larvae and pupae (Thomas 1965). The scientific name, *D. ponderosae*, and common name, mountain pine beetle, were retained. However, some forest entomologists doubted that *jeffreyi* should be synonymized with *ponderosae*. Some reported that the Jeffrey pine beetle is limited to Jeffrey pine (Keen 1952; Eaton 1956). Vapor toxicity studies (Smith 1963, 1965) demonstrated Jeffrey pine beetles tolerated saturated resin vapors of Jeffrey pine, but not those of ponderosa pine, whereas mountain pine beetles tolerated vapors of ponderosa pine resin, but not those of Jeffrey pine. Additional evidence for the synonymy of *ponderosae* and *monticolae* and the distinctiveness of *jeffreyi* was obtained through laboratory matings and comparison of developmental rates, karyology, and morphology (Lanier and Wood 1968).

Recent pheromone studies further support maintaining the two species. One-heptanol, produced by oxidation of the terpene heptane in Jeffrey pine, is a pheromone involved in aggregation of *D. jeffreyi* (Renwick and Pitman 1979). *Trans*-verbenol, produced by oxidation of the host terpene alpha-pinene, appears to be the principal pheromone involved in aggregation of *D. ponderosae* in western white and ponderosa pines (Pitman and others 1968). Heptane constitutes about 90 percent of the volatile fraction of resin from Jeffrey pine, whereas alpha-pinene constitutes 32 to 60 percent of the volatile resin fraction from western white pine, but varies from 1 to 45 percent in ponderosa pine (Mirov 1961).

A genetic comparison of mountain pine beetles and Jeffrey pine beetles from northern California supports their separate species designations. Two loci are fixed for different alleles in the two species, strongly suggesting the absence of interbreeding (Higby[3]). These findings support the separation into two species—*D. ponderosae* and *D. jeffreyi*.

Genetic studies of mountain pine beetles also demonstrate differences between populations in *Pinus contorta* var. *murrayana* and *P. contorta* var. *latifolia*, probably related to longtime geographic isolation of populations in the two hosts (Stock and others 1978). Genetic analysis of several widely separated beetle populations in Idaho and Montana further suggests that genetic differentiation within this species is generally associated with geography (Stock and Guenther 1979); however, genetic differentiation among beetle subgroups in local areas is at least partly related to host tree species (Stock and Amman 1980).

Distribution and Host Trees

The beetle is found from the Pacific Ocean eastward through the Black Hills of South Dakota, and from about 56° north latitude in northern British Columbia southward to northwestern Mexico. The beetle occurs from about sea level in British Columbia to 11,000 ft (3 333 m) in Colorado (McCambridge and Trostle 1972; Safranyik 1978) (fig. 1).

The most important hosts of the mountain pine beetle from the standpoint of timber production are ponderosa, western white, sugar, and lodgepole pines. In addition, Coulter (*P. coulteri* D. Don), whitebark (*P. albicaulis* Engelmann), limber, pinyon (*P. edulis* Engelmann), bristlecone (*P. aristata* Engelmann), and foxtail (*P. balfouriana* Greville and Balfour) pines can be infested (Wood 1963). Brood is not usually produced in the occasionally infested nonhost tree—Engelmann spruce, grand fir (*Abies grandis* Lindl.), and incense-cedar (*Libocedrus decurrens* Torrey) (Evenden and others 1943). However, successful brood production by mountain pine beetles occurred in fairly widespread killing of mature and

[1] "Beetle" refers to mountain pine beetle throughout this report unless otherwise noted.

[2] Blackman, M. W. Report on an examination of *Dentroctonus ponderosae* and *D. monticolae*. Washington, DC: U.S. Bureau of Entomology and Plant Quarantine, Forest Insect Investigations; 1938. 6 p. Unpublished report.

[3] Higby, Pamela K. Genetic relationships between two sibling bark beetle species, Jeffrey pine beetle (*Dentroctonus jeffreyi* Hopkins) and mountain pine beetle (*D. ponderosae* Hopkins), in northern California. Moscow, ID: University of Idaho; 1981. 50 p. Thesis.

overmature Engelmann spruce in the Flathead River Drainage and in three locales on the Gallatin National Forest of Montana (Mark D. McGregor, Forest Service, Missoula, Mont., personal communication, December 11, 1979). Brood is seldom produced in blue spruce, *P. pungens* Engelmann (Beal 1939). In addition to infesting native trees, a few beetles were produced from infested Norway spruce (*Picea abies* [Linnaeus] Karsten) in a University of Idaho arboretum (Furniss and Schenk 1969). Other exotics infested and killed included Scots pine, *P. sylvestris* L.; eastern white pine, *P. strobus* L.; red pine, *P. resinosa* Aiton; jack pine, *P. banksiana* Lambert; Austrian pine, *P. nigra* Arnold; and pitch pine, *P. rigida* Miller (Furniss and Schenk 1969). The mountain pine beetle apparently showed preference for exotic species of pine over native species, because neither *P. ponderosa* nor *P. monticola* was infested in the arboretum.

Ornamental Scots pines also were killed by the mountain pine beetle in Fort Collins, Colo., with beetles probably flying from infested ponderosa pine forests 7 or more miles away (McCambridge 1975). The beetles showed preference for Scots pine over adjacent Austrian and ponderosa pines, none of which were infested. Additional exotic or hybrid pines killed by mountain pine beetles at the Institute of Forest Genetics in California were cher pine, *P. roxburghii* Sargent; bishop pine, *P. muricata* D. Don; Japanese red pine, *P. densiflora* Sieb. and Zucc.; shortleaf-loblolly hybrid, *P. echinata* Mill. x *taeda* L.; and loblolly-slash hybrid, *P. taeda* x *elliottii* Engelmann var. *elliottii*. Adjacent ponderosa pine, as in Idaho and Colorado, were not attacked (Smith and others 1981).

The ability to attack and kill and even produce brood in some of the usually regarded nonhost trees, particularly climax species, would appear to aid the mountain pine beetle in maintaining forests of preferred species consisting of lodgepole, ponderosa, and western white pines.

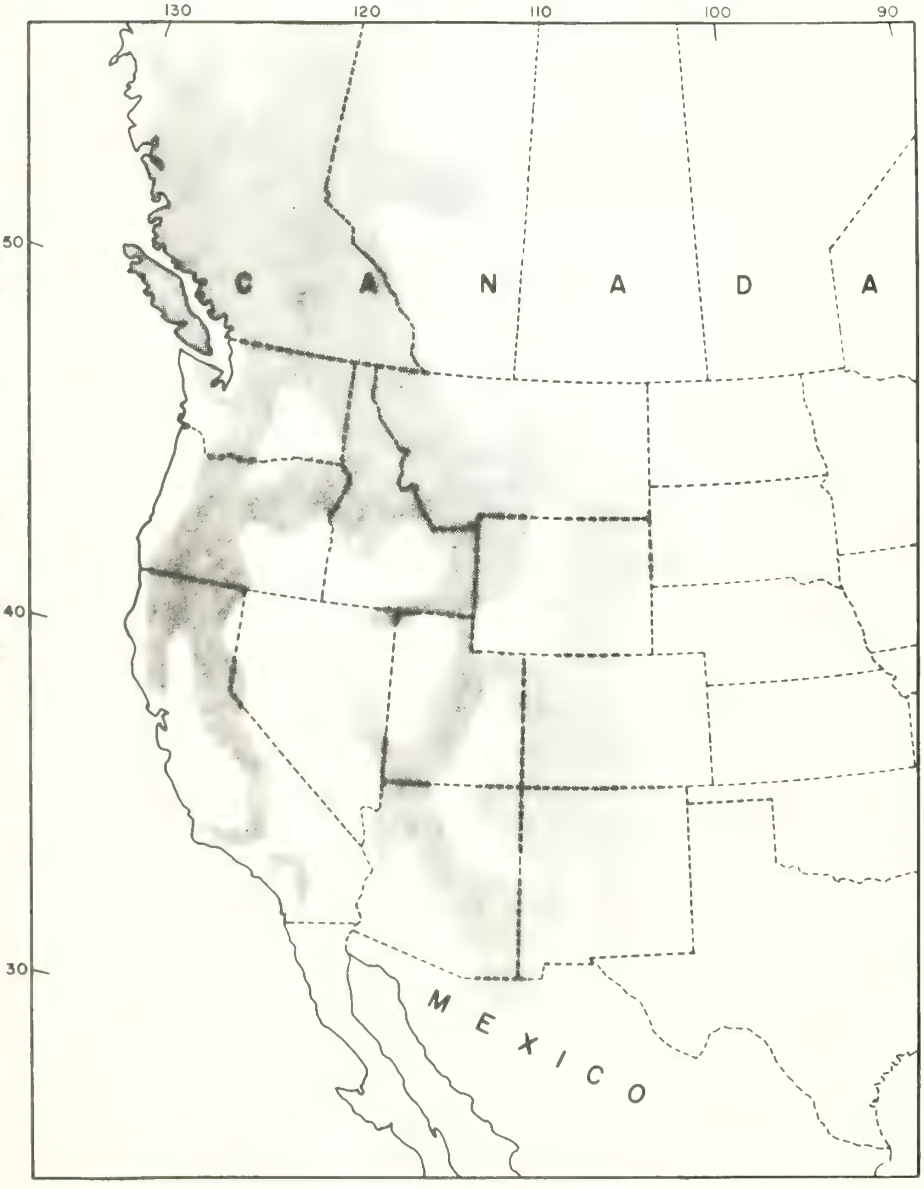

Figure 1.—Approximate distribution of the mountain pine beetle in North America (McCambridge and Trostle 1972).

Description

The egg is ovoid, white to cream colored, as shown in figure 2a. (Figure 2 is on the inside front cover). A sample of 20 eggs from lodgepole pine in northern Utah averaged 0.04 inch long (1.02 mm; sd = 0.10 mm) and 0.02 inch wide (0.51 mm; sd = 0.02 mm). However, cross-sectional area and weight of eggs are significantly related to beetle size, with the largest beetles producing the largest eggs (McGhehey 1971). Unfertilized eggs remain a uniform color, whereas fertilized eggs develop a clear area in one end during early embryogenesis.

The mountain pine beetle has four larval instars (fig. 2b). Larvae are white to cream colored, with amber head capsules. Head capsules are between 0.014 inch (0.36 mm) and 0.065 inch (1.64 mm) (fig. 3). Average head capsule width for the four instars from lodgepole pine are: I = 0.019 inch (0.493 mm; sd = 0.037 mm); II = 0.026 inch (0.653 mm; sd = 0.041 mm); III = 0.037 inch (0.950 mm; sd = 0.075 mm); and IV = 0.049 inch (1.240 mm; sd = 0.081 mm).

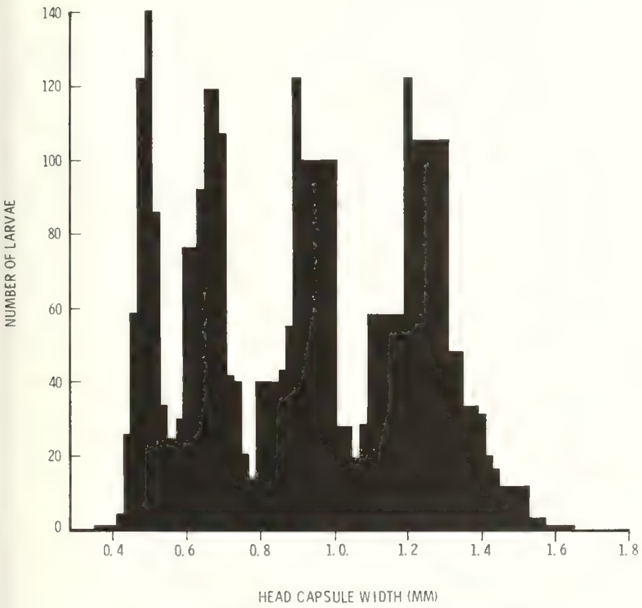

Figure 3.—Head capsule distribution of mountain pine beetle larvae.

The pupa is white to cream colored and of the general form and size of the adult. Legs and wing pads are folded beneath the body, and the abdominal segments are exposed (fig. 2c). The pupa is the earliest stage in which the sexes can be readily differentiated. Females have a protruding lobe between the eighth sternite and ninth tergite (fig. 4); the lobe is lacking in males (Schofer and Lanier 1970).

Adults are light tan and soft at first (commonly called teneral or callow adult), becoming dark brown to black and hard prior to emergence. Adults are stout, cylindrical, and average about 0.20 inch (5 mm) long (fig. 2d). Females are usually longer than males. For example, for beetles caught in cages during the 1973 flight on the Wasatch-Cache National Forest in Utah, the average length of females was 0.20 inch ($\bar{x}$ = 5.13 mm; sd = 0.42 mm; N = 426), and that of males was 0.19 inch ($\bar{x}$ = 4.73 mm; sd = 0.36 mm; N = 186).

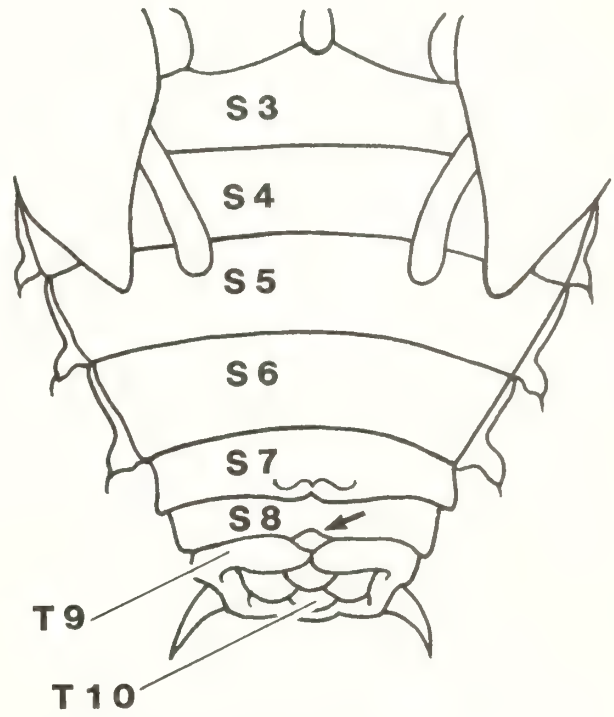

Figure 4.—Ventral aspect of female *Dendroctonus* pupa. Lobe indicated by arrow is a character of females; the lobe is absent in males (Schofer and Lanier 1970).

Sexual dimorphism of the seventh abdominal tergite in adult beetles permits easy separation of the sexes (Hopkins 1909; Lyon 1958). In males, the posterior margin of the tergite forms an angle of about 150° pointing to the rear; in females, the margin is gently rounded to the rear (fig. 5). The pointed margin of the male is used for stridulation (sound production used in communication) when the tergal plectrum is pulled across the file located on the underside of the elytra. Electron micrographs of the file and oscillograms of typical male chirps were made by Michael and Rudinsky (1972). The sound can be used to separate the sexes because males usually make a more continuous and audible sound than females (McCambridge 1962).

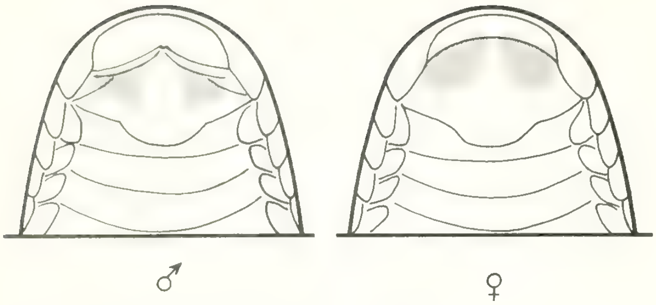

Figure 5.—Schematic, dorsal view of exposed, rear part of adult *Dendroctonus* abdomen. Left: male with angular rear margin of enlarged seventh tergite. Right: female with gently curved rearward margin (Lyon 1958).

Life Cycle

The typical 1-year beetle life cycle starts with emergence of new adults in middle to late July and early August, as shown in figure 6. (Figure 6 is on the front cover). Adults select and infest green trees, then construct vertical egg galleries. Eggs are laid in niches arranged singly in alternate groups along the sides of the gallery. Eggs hatch within a week or so, and the larvae feed in the phloem, usually making tunnels at right angles to the egg gallery. Larvae may reach the third and early fourth stages before cold weather in late October and November when they become dormant. They resume feeding in April, completing larval development in June. Larvae pupate within cells excavated in the bark and sapwood. Pupae transform into adults during the latter part of June to mid-July. New adults feed within the bark prior to emergence.

Several notable exceptions to the typical life cycle are created primarily by climatic differences and varying weather. New adults that mature and emerge early in a warm year may make two galleries (Reid 1962a). After infesting one tree and completing egg galleries, they emerge and infest a second tree. This phenomenon has been relatively uncommon in lodgepole pine forests south of Montana. Trees along Hell Roaring Creek in the Gallatin Canyon of Montana showed a high rate of parent reemergence in 1973. Although these parents then attacked and killed additional trees, it is doubtful that many progeny were produced because attacks came so late in the fall that few eggs hatched. Insufficient heat units occur for all eggs to hatch when beetles infest trees in late August (Reid and Gates 1970). All eggs and many small larvae that enter the winter are killed by the cold (Amman 1973). Eggs freeze at minus 0.6° F (-18° C) (Reid and Gates 1970).

A high proportion of parent beetles may survive mild winters within egg galleries they constructed during late summer and fall of the previous year. Only a few of these beetles appear to emerge and infest trees before their progeny emerge. Most often, early emerging parents will construct a gallery in green phloem on trees that had only a vertical strip of the bark infested previously (strip attack), or trees that resisted attack with a copious flow of resin (pitchout) that forced the beetles to abandon their galleries the previous year (Rasmussen 1974). Most parents that survive the winter probably emerge the same time as their progeny. This parental behavior is indicated by few or no parent emergence holes (those originating from egg galleries) and the few to no trees infested prior to emergence of progeny.

Parent beetles may extend their galleries and continue oviposition in the spring in green phloem tissue or tissue that has not deteriorated from micro-organisms introduced by the beetles.

Beetles may require 2 years to complete a generation at high elevations such as in western Montana and central Idaho (Evenden and others 1943; Gibson 1943), as well as at elevations above 8,000 ft (2 400 m) at 43° N latitude, 110° W longitude in northwestern Wyoming (Amman 1973). The beetle required 2 years to complete a generation in Banff National Park, Alberta, in 1956 (Reid 1962a). Previously, a generation had been completed in a single year in the park. The delaying effect that cool temperatures have on development and emergence of beetles is largely responsible. The life cycle of the beetle thus varies from year to year and place to place according to elevation, latitude, longitude, and weather differences.

BIOLOGY AND BEHAVIOR

Preemergence, Emergence, and Flight

Prior to emergence, new adults feed within the bark to complete maturation. During this feeding period, flight muscles increase in size and can be used to forecast when beetles are physiologically ready to emerge (McCambridge and Mata 1969). While feeding, adults also obtain fungal and yeast spores (Shifrine and Phaff 1956) and probably bacteria in the maxillary mycangium (a special structure for transporting spores) for inoculating fresh host material (Whitney and Farris 1970). A limited amount of mating may occur prior to emergence; 2 percent of newly emerged females contained sperm (McCambridge 1970).

When the density of new adults is high, their feeding chambers may coalesce. Then when a beetle chews an exit hole through the bark to emerge, all beetles within the common chamber emerge through the single hole (Reid 1963; Amman 1969). New adult densities of 1 to 20 beetles/ft^2 (930 cm^2) of bark surface average 1 beetle per emergence hole. At greater densities, the number of beetles emerging per hole increases geometrically, with an average of about 2 beetles per hole at densities of 200 beetles/ft^2 (930 cm^2) of bark surface (fig. 7).

Emergence and flight of new adults usually begin after relatively high temperatures and abundant sunshine (Reid 1962a; Rasmussen 1974). Emergence occurs only during the warm part of the day, starting when temperatures reach about 60° F (15.5° C), and ceasing in the afternoon when temperatures drop to about the same level (Reid 1962a; Rasmussen 1974). When beetles emerge, they are positively phototactic (Schonherr 1971; Shepherd 1966). Maximum flight activity generally occurs from 4 p.m. to 6 p.m. (mountain daylight time) in the mountains of Arizona, Colorado, Idaho, and Utah, in both lodgepole and ponderosa pine forests (Blackman 1931; McCambridge 1967, 1971; Rasmussen 1974) (table 1). Maximum flight activity farther north in Washington and British Columbia is earlier—from 11 a.m. to 4 p.m. in both ponderosa and lodgepole pine forests (Gray and others 1972; Reid 1962a). Flight may begin earlier in Washington and British Columbia because the threshold temperature may occur earlier in the day.

Emergence may be controlled, at least partially, by factors other than temperature. Watson (1970) found that a rhythmic and possibly circadian emergence cycle occurred for mountain pine beetles from lodgepole pine in Canada when reared in total darkness and at a constant temperature. Emergence was greatest between 9 a.m. and 3 p.m., which was similar to field

results (Reid 1962a). A circadian emergence rhythm has also been suggested for mountain pine beetles in ponderosa pine (Billings and Gara 1975).

Beetles flying late in the day to green lodgepole pine trees remain in bark crevices and under bark scales until the following day (Rasmussen 1974). These beetles then either bore into the tree or take flight after air temperature reaches about 63° F (17° C) the following day. However, some beetles bore into ponderosa pine during the night (McCambridge 1974). This difference in behavior is probably related to generally warmer night temperatures in ponderosa stands, which are usually at lower elevations than lodgepole pine stands.

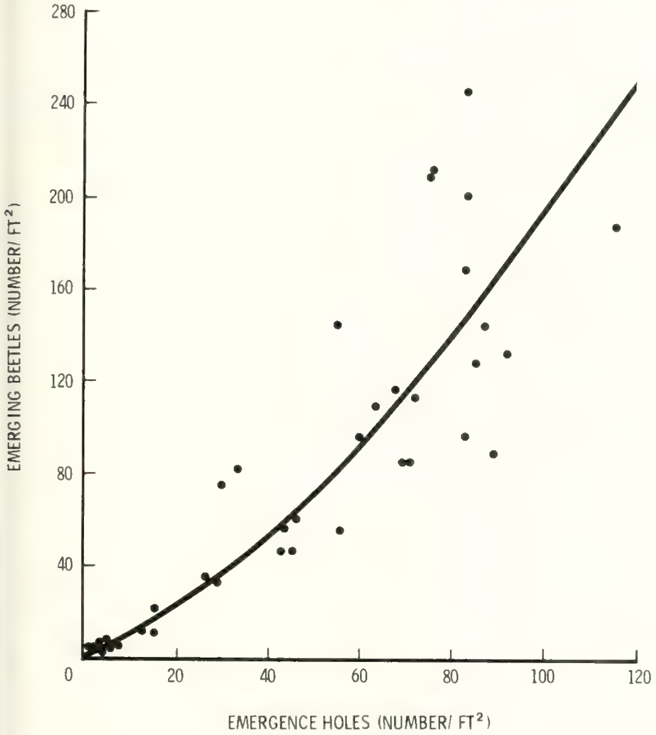

Figure 7.—The number of mountain pine beetles emerging per emergence hole increases as the density of beetles increases. (See regression statistics in appendix.)

Table 1.—Peak emergence and flight of mountain pine beetles in different portions of the beetles' range

Observer	Temperature	Time	Host	Locality
	°C			
Rasmussen (1974)	23	4 p.m.-6 p.m.	Lodgepole	Utah, Idaho
Reid (1962a)	22	1 p.m.-4 p.m.	Lodgepole	British Columbia
Shepherd (1966)	22	—	Lodgepole	British Columbia
Blackman (1931)	—	4 p.m.-dusk	Ponderosa	Arizona
Gray and others (1972)	20	11 a.m.-2 p.m.	Ponderosa	Washington
McCambridge (1971)	20	4 p.m.-6 a.m.	Ponderosa	Colorado

Beetles emerge at a greater relative rate from south than north aspects of trees, and at a greater rate low than high on the stem (Safranyik and Jahren 1970a). Temperature probably is responsible for the differences among aspects, since subcortical temperatures are usually higher on south than north aspects of the tree (Powell 1967). However, it does not explain the greater rate of emergence lower on the bole because temperatures in a lodgepole stand tend to increase with tree height (Bergen 1974).

Emergence and flight may be diminished when temperatures are too high. Gray and others (1972) and Rasmussen (1974) found that activity was reduced on days when air temperature reached or exceeded 90° F (32° C). In laboratory studies, adult beetles became photonegative between 95° and 99.5° F (35° and 37.5° C) (Shepherd 1966).

Emergence may last several weeks, with only a few beetles emerging at the beginning and end. After a period of sparse, sporadic emergence, the majority of beetles usually emerge and attack in about 1 week (fig. 8) (Rasmussen 1974). Emergence period varies from year to year as a result of rate of beetle development (McCambridge 1964) and weather during the emergence cycle.

In northern Utah, peak numbers emerged during 7 days in 1970, 9 days in 1971, and 7 days in 1972. Frequent light thunderstorms may have lengthened peak emergence in 1971 because beetles remain in the trees during such weather (Rasmussen 1974). The rapid emergence of most of the population is essential to the success of the mountain pine beetle in attacking and killing the most vigorous trees in lodgepole pine stands.

Males and females emerge in about equal numbers during the early and late portions of the emergence cycle, but females predominate during midcycle (Rasmussen 1974, 1980) (fig. 9). Similar results were obtained from laboratory rearings (fig. 10). Females emerging during the first half of the emergence cycle are larger than those emerging later (Safranyik and Jahren 1970a; Rasmussen 1980) (fig. 11).

Emergence of beetles from thin phloem is delayed and at a slower rate than emergence from thick phloem in the laboratory. Approximately 50 percent of the population emerged after 6 days from thick phloem, whereas it took 16 days for that proportion to emerge from thin phloem (fig. 12). Delayed emergence is critical because time of attack and oviposition determines how far larvae will develop prior to winter. Eggs and many small larvae are killed by cold (Amman 1973).

Safranyik and Jahren (1970b) investigated the relation of mountain pine beetle size to tree diameter, height and aspect on the stem, bark thickness, moisture content of the outer sapwood, and brood density. Generally the average pronotal widths of emerging males and females were inversely related to height on the stem, with the largest beetles occurring at 4 to 6 ft (1.2 to 1.8 m) above ground. Beetle size was not related to north or south aspects, but sizes of both sexes were positively correlated with tree diameter. In addition, size was correlated with bark thickness and moisture content of the outer sapwood in 1 of the 2 years of the investigations.

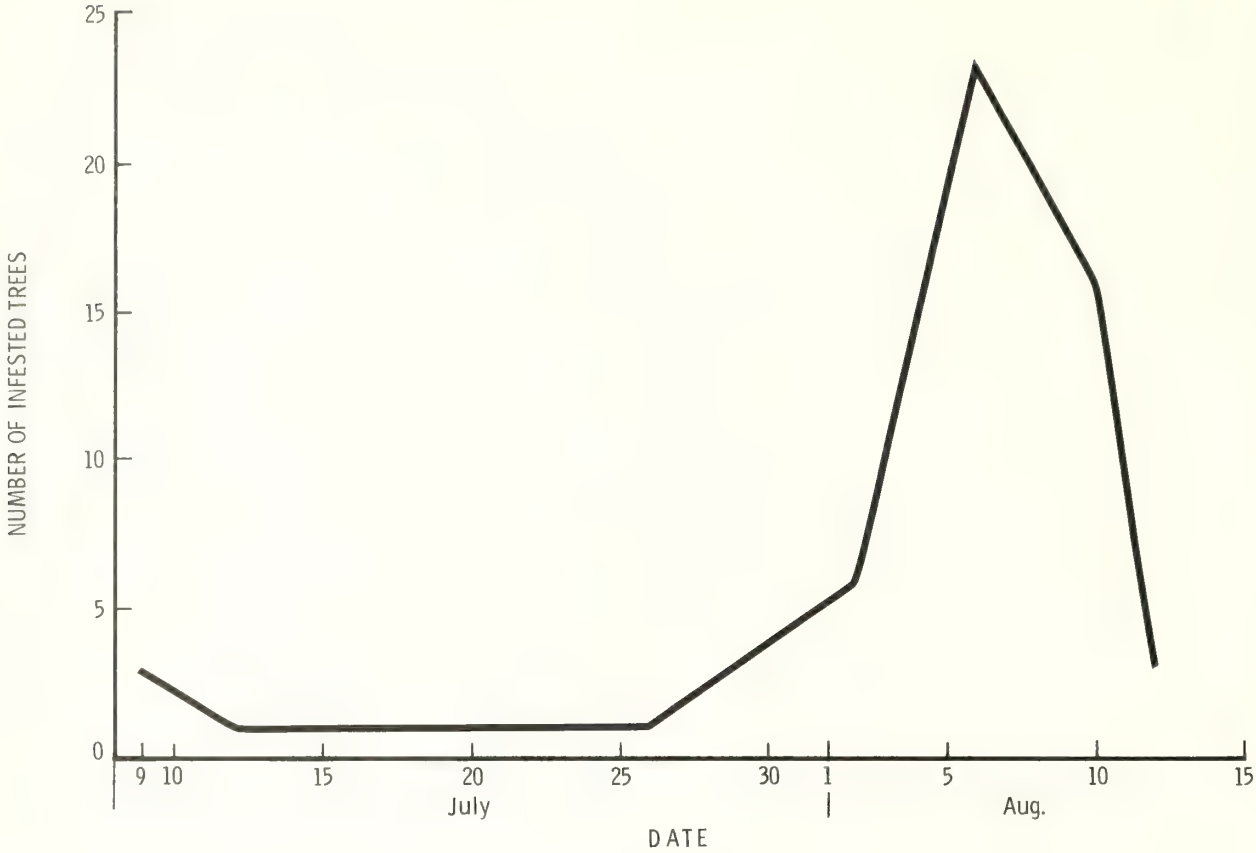

Figure 8.—Numbers of trees attacked by date during the 1971 flight period, Wasatch National Forest, Utah.

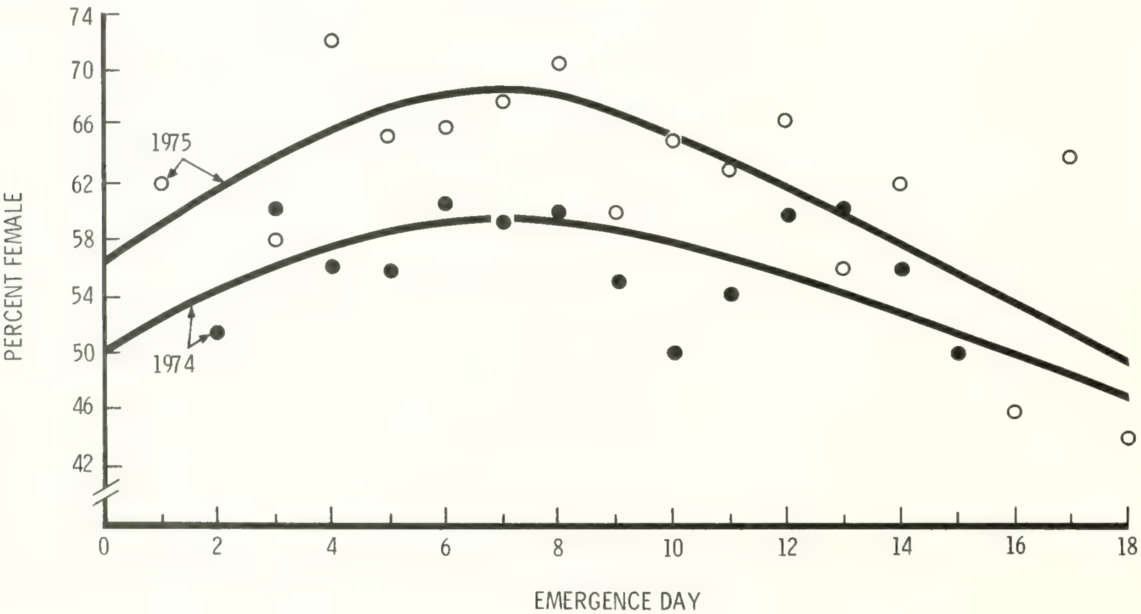

Figure 9.—Percent of emerging mountain pine beetles that were female in relation to day of emergence for 1974 and 1975 (Rasmussen 1980). (See regression statistics in appendix.)

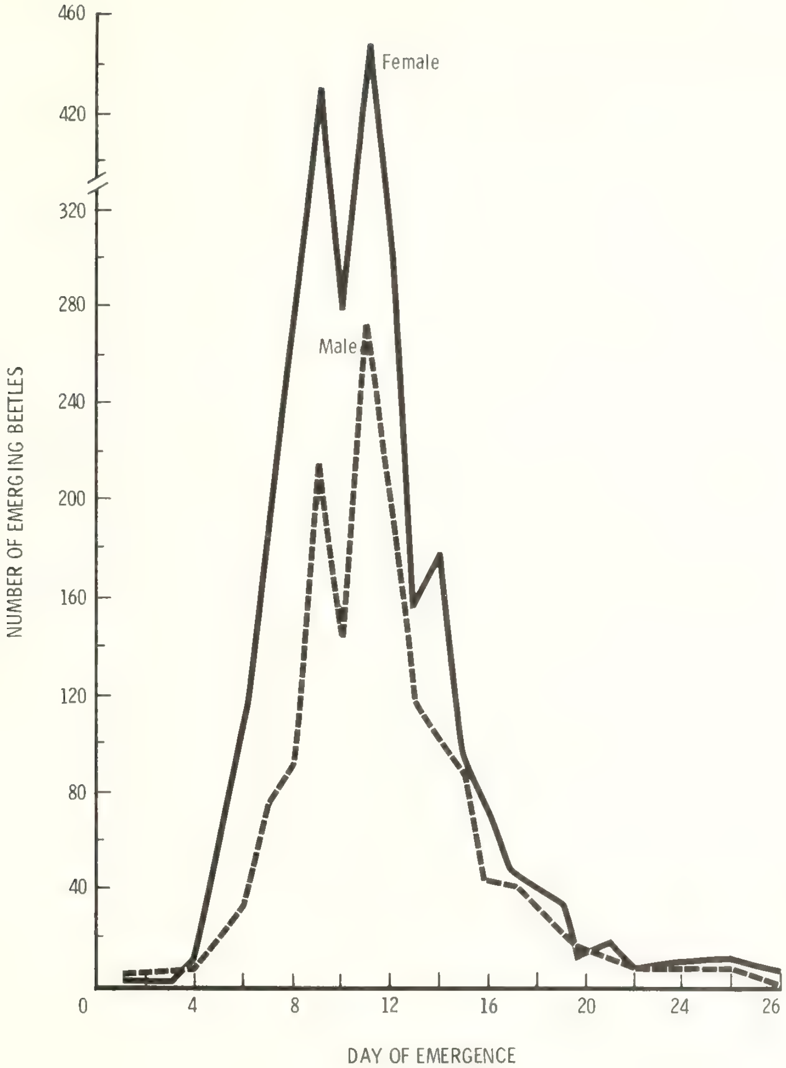

Figure 10.—Emergence cycle of male and female mountain pine beetles in a laboratory population.

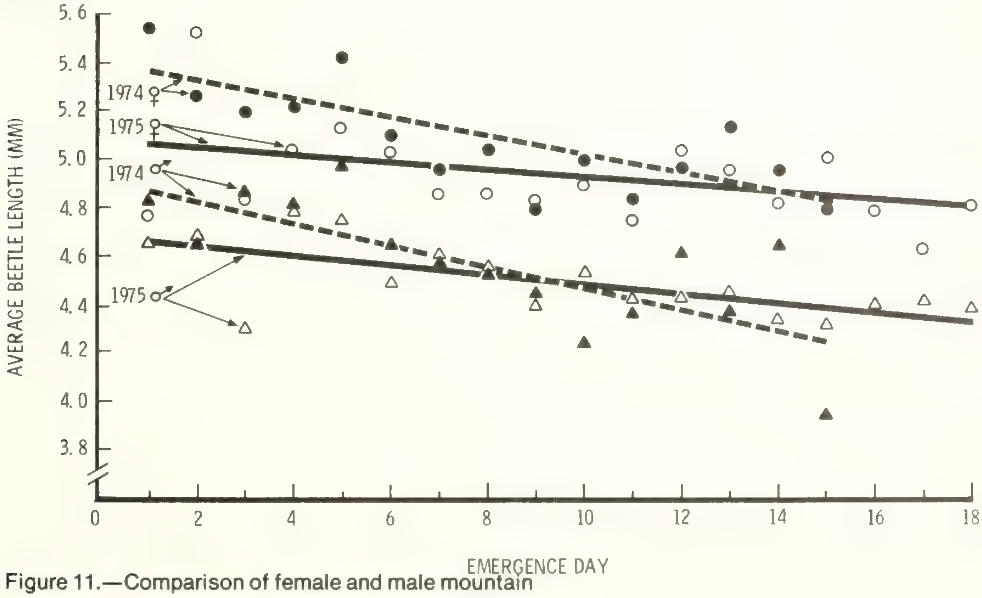

Figure 11.—Comparison of female and male mountain pine beetle size in relation to emergence day for 1974 and 1975, Logan Canyon plot, Wasatch-Cache National Forest, Utah (Rasmussen 1980). (See regression statistics in appendix.)

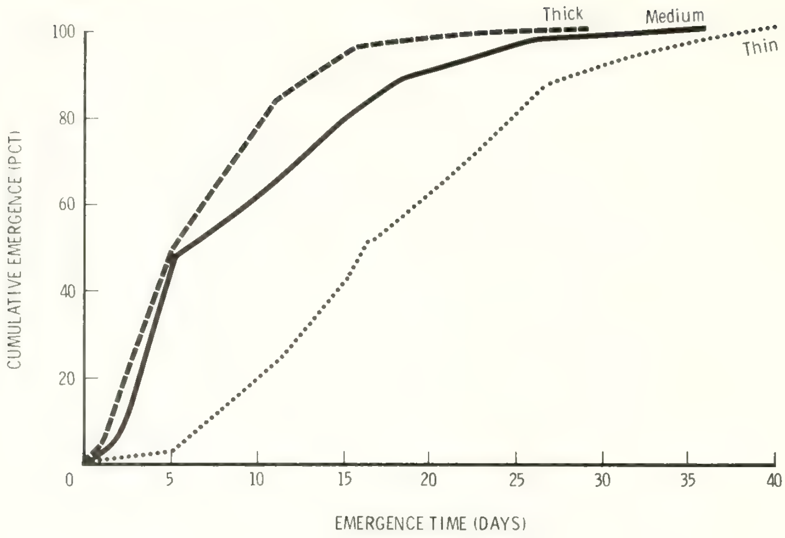

Figure 12.—Rate of mountain pine beetle emergence from three phloem thickness categories in a laboratory population.

Beetle size differed according to rearing temperature in the laboratory (table 2). Females reared at a constant 77° F (25° C) were significantly ($P \leq 0.001$) smaller than those reared at 59° or 68° F (15° or 20° C). However, this was not the case with males, which were smaller when reared at both 68° and 77° F (20° and 25° C) than when they were reared at 59° F (15° C). There was no significant difference in size of males reared at 68° and 77° F (20° and 25° C).

Table 2.—Length of new adult mountain pine beetles reared at three constant temperatures

Temperature	Male length			Female length		
	x̄[1]	sd	n	x̄	sd	n[1]
°C	--- mm ---			--- mm ---		
15	4.55	0.32	30[2,1]	5.19	0.37	61[1]
20	4.53	.34	99[1]	5.01	.37	202[2]
25	4.28	.34	26[2]	4.95	.30	90[2,1]

[1]Means having the same number are significantly different at the 0.001 level of probability.

In a second study, parents were introduced in logs from a single tree, and the logs then placed at different elevations on the north slope of the Uinta Mountains in Utah. New adults completing development in cooler temperature regimes were larger (table 3).

The larger size of Douglas-fir beetles, *D. pseudotsugae* Hopkins, reared at cool, in contrast to warm, temperature was shown by Atkins (1967). In addition, Atkins found that beetles reared at cool temperatures had proportionately greater lipid content than those reared at warmer temperatures.

Table 3.—Length of new adult mountain pine beetles reared at four elevations in northern Utah

Elevation		Male length[1]			Female length[1]		
		x̄	sd	n	x̄	sd	n
Feet	*m*	--- *mm* ---			--- *mm* ---		
8,600	(2,621)	4.66	0.40	43	5.21	0.44	79
9,000	(2,743)	4.83	.33	38	5.40	.46	109
9,400	(2,865)	4.94	.35	60	5.48	.38	200
9,800	(2,987)	5.20	.39	121	5.70	.41	194

[1]All means were significantly different from one another at the 0.001 level.

Beetle size also has been related to phloem thickness. Beetles reared in thick phloem were significantly larger than those reared in thin phloem (table 4, $P \leq 0.001$) at all egg gallery densities ($P \leq 0.005$) (fig. 13) (Amman and Pace 1976). A difference in beetle size among tree diameters is apparent throughout most of an infestation cycle (table 5); both males and females from the largest trees are almost always larger (fig. 14). The principal reason probably is the greater thickness of phloem as food for developing larvae, and possibly greater nutritional value found in large than in small trees (Amman 1969, 1975b, 1978).

Table 4.—Length of new adult mountain pine beetles reared in lodgepole pine billets having thin or thick phloem

Phloem thickness	Male length			Female length		
	x̄	sd	n	x̄	sd	n
	---- *mm* ----			---- *mm* ----		
Thin	4.45[1]	0.381	26	4.98[1]	0.344	33
Thick	4.71	.272	81	5.25	.354	85

[1]Means for thin and thick phloem are significantly different for both sexes at the 0.001 level of probability.

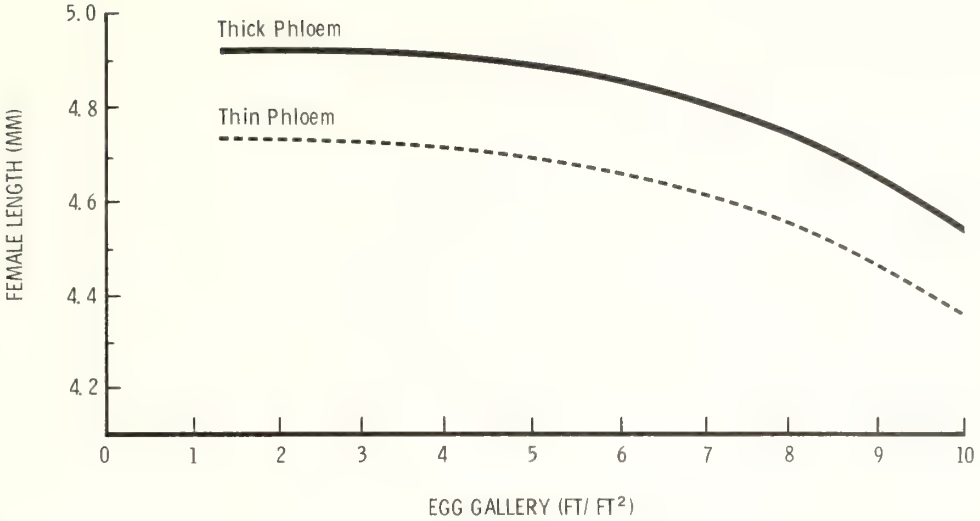

Figure 13.—Length of mountain pine beetle females in relation to egg gallery density for two phloem thickness categories (Amman and Pace 1976). (See regression statistics in appendix.)

Table 5.—Average lengths of male and female mountain pine beetles from different lodgepole pine diameter classes and years, Wasatch-Cache National Forest

Year	<8.9 inches (22.6 cm)		9.0-10.9 inches (23-27.7 cm)		11.0-13.9 inches (27.9-35.3 cm)		>14 inches (35.6 cm)	
	♂	♀	♂	♀	♂	♀	♂	♀
				mm				
				Stillwater Plot				
1968	--	--	--	--	--	--	4.77	5.26
1969	--	--	3.72	4.02	--	--	4.02	4.39
1970	--	--	4.11	5.05	4.75	5.15	5.01	5.23
1971	--	--	4.59	5.11	4.65	5.45	4.83	5.36
1972	--	--	4.58	5.26	4.50	5.15	4.71	5.31
1973	--	--	4.69	5.10	4.62	5.15	4.84	5.31
1974	4.52	4.55	4.48	5.08	4.72	5.12	4.89	5.18
1975	4.56	4.92	4.76	5.02	4.46	4.98	4.46	5.10
1976	--	--	4.60	5.17	4.56	5.17	4.56	5.10
1977	4.49	4.93	4.81	4.85	4.47	4.98	--	--
1978	4.41	4.38	4.58	4.89	4.49	4.91	4.50	4.92
1979	4.23	--	--	4.49	4.58	4.84	4.34	4.23
Grand average	*4.44*	*4.59*	*4.49*	*4.91*	*4.58*	*5.07*	*4.63*	*5.04*
				Logan Canyon Plot				
1971	4.20	4.18	--	4.92	4.56	4.43	--	--
1972	4.20	4.67	4.52	4.95	4.59	5.18	4.82	5.24
1973	—	--	4.40	4.87	4.47	4.86	4.53	5.10
1974	--	4.48	4.35	4.73	4.47	5.02	4.78	5.19
1975	4.25	4.76	4.37	4.78	4.20	4.57	4.39	4.75
1976	4.25	4.68	4.44	4.76	4.41	4.81	4.47	4.86
1977	--	--	--	--	4.49	5.13	4.60	5.09
1979	3.77	4.49	4.53	4.85	4.70	5.19	4.73	5.11
Grand average	*4.13*	*4.57*	*4.44*	*4.84*	*4.49*	*4.90*	*4.62*	*5.05*

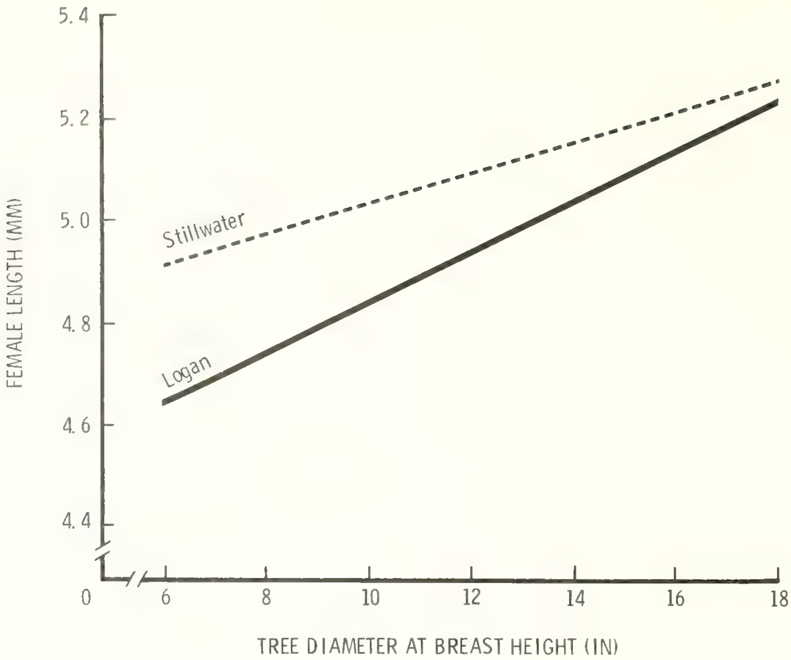

Figure 14.—Length of female mountain pine beetles increased with diameter at breast height of lodgepole pine in the Logan Canyon and Stillwater plots, Wasatch-Cache National Forest for years 1971-78 and 1968-79 respectively. (See regression statistics in appendix.)

Most mountain pine beetles fly at a level corresponding to the midbole of lodgepole pine in both thinned and unthinned stands. Beetle catches in nondirectional barrier traps revealed that, overall, 35 percent of beetles were caught at a height of 6 ft (1.8 m) above ground; 48 percent at midbole height, about 25 ft (7.6 m); and 17 percent at midcrown height, about 45 ft (13.7 m) (Schmitz and others 1980). Greater catches at midbole may result from less understory vegetation and tree branches than at the other two levels.

Flight tests showed that newly emerged beetles generally flew with the wind when pheromones were absent. However, in the presence of synthetic *trans*-verbenol and freshly cut host material, flight was toward the attraction source and against the wind (Gray and others 1972).

Host Selection and Infestation

The mountain pine beetle usually selects the largest trees in the stand to infest, at least during the few years preceding and during a major epidemic (Cole and Amman 1969; Evenden and Gibson 1940; Hopping and Beale 1948). Beetles use both visual and chemical cues when infesting these trees. In laboratory studies, the mountain pine beetle was attracted to large dark objects (simulating the large diameter trees) against a light background as shown by Shepherd (1966). He suggested that the beetle uses vision in selecting trees to infest. Further evidence of this is furnished by Rasmussen (1972), who attempted to attract mountain pine beetles to small diameter trees by baiting them with *trans*-verbenol and alpha-pinene. Beetles were attracted into the area of the baited tree, but usually selected a nearby tree of large diameter. Among trees of similar diameter, beetles infested those that had the thickest phloem (Roe and Amman 1970). This suggests that the beetle may also use chemical cues from the tree in selecting its host when little difference in tree size exists. Terpenes occur in greater quantity in thick than in thin phloem (fig. 15), and, because of the volatility of the monoterpenes, could be the olfactory stimulus used by beetles to locate trees having thick phloem (Cole and others 1981).

A random landing (Hynum and Berryman 1980) and attack pattern (Burnell 1977) have been proposed. Hynum and Berryman (1980) trapped landing beetles on both living and dead lodgepole pines and on live Douglas-fir trees. Catches among the three types of trees were not significantly different; therefore, they concluded the mountain pine beetle landed at random on trees. However, Hynum and Berryman's data show a high mean catch with low numbers of observations on nonhost trees compared to low mean catch and large numbers of observations on lodgepole pine. This suggests that increased sample size may have demonstrated a significant difference in catch, with a preference shown for landing on Douglas-fir, a nonhost tree. The sizes of Douglas-fir on which traps were placed were given only as medium and large. Large Douglas-fir trees may have served as large dark objects that laboratory studies demonstrated to be more attractive to mountain pine beetles than are small dark objects (Schonherr 1976; Shepherd 1966). In addition, dark-colored bark (Schonherr 1971) and texture (Shepherd 1965) may have been factors that further influenced initial landing rates of mountain pine beetles.

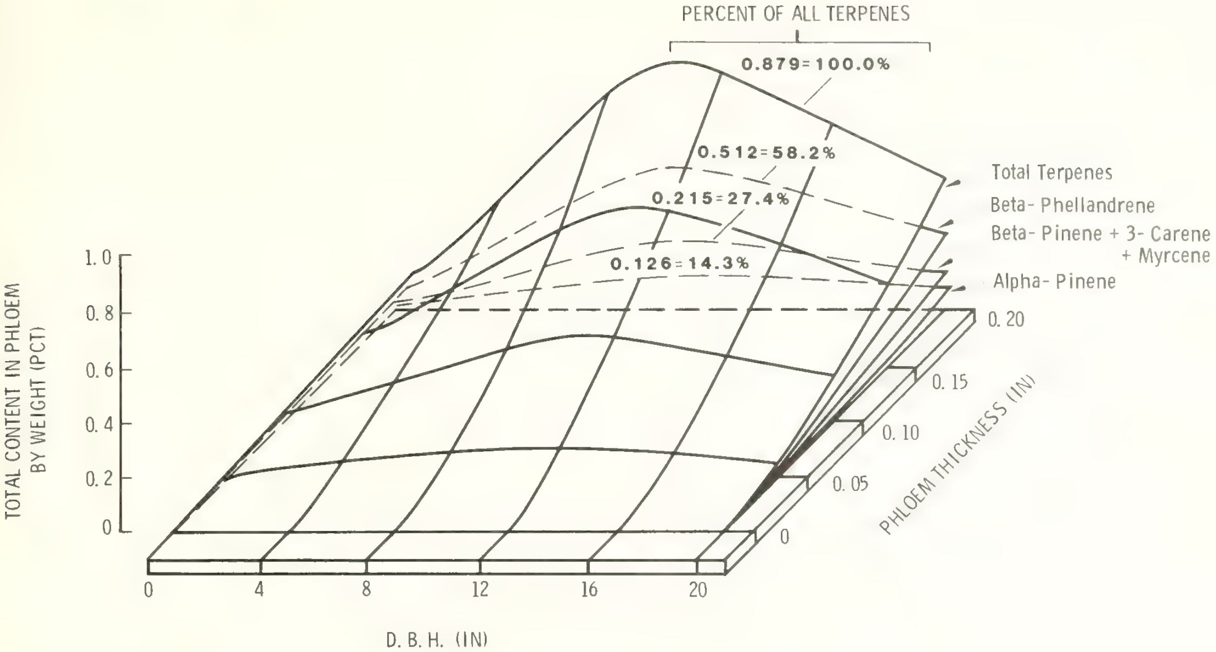

Figure 15.—Monoterpenes in lodgepole pine increase with phloem thickness and diameter.

Random landing, however, does not necessarily mean random attack, but possibly only a necessary resting or shelter spot for the night when temperatures or light conditions fall below the threshold required for flight. Beetles do spend the night on some trees without boring into them (Rasmussen 1974). The next day, they take flight when the temperature threshold is reached.

Hynum and Berryman (1980) further postulate that beetles determine suitable hosts by first nibbling the bark to detect a compound that induces gallery initiation. They state that gallery initiation stimulants appear to be the controlling factor in the host selection process, and these are unrelated to diameter. However, Raffa and Berryman (1982) were unable to demonstrate feeding differences on extracts from trees they considered resistant or susceptible to mountain pine beetle attack.

The idea of beetles being attracted visually to trees on the basis of size (Shepherd 1966) and perhaps olfactorily to higher proportions of terpenes found in large trees (Cole and others 1981) is consistent with most studies of lodgepole pine mortality, losses being highest in the large diameters (Cole and Amman 1969; Evenden and Gibson 1940; Hopping and Beale 1948; Klein and others 1978; Parker 1973; Roe and Amman 1970; Safranyik and others 1974).

The response to large diameter trees is probably related to the greater chance of encountering thick phloem, and hence greater brood survival (Amman 1969, 1975b). Ratios of emerging brood adults to attacking parent adults are much higher in large than in small diameter lodgepole pines (Cole and Amman 1969; Klein and others 1978; Safranyik and others 1974).

After alighting on a lodgepole pine, most female beetles move upward, often obliquely (Rasmussen 1974). They examine many bark scales and crevices before initiating an egg gallery. Beetles avoid smooth areas and burrow into the bark under scales and crevices (Rasmussen 1974). Initial attacks occurred under bark scales 61 percent of the time, and in bark crevices 39 percent of the time. When beetles fail to find an acceptable niche, even on attacked trees, they may take flight after searching less than 30 minutes.

The female that has completed flight and just initiated her gallery has large flight muscles, expanded fat body, reduced reproductive system, and the digestive tract is empty, characteristics necessary for flight (Reid 1958b; 1962b). Following initiation of the egg gallery and mating, the flight muscles and fat body atrophy, and the reproductive and digestive systems increase in size (Reid 1958b; 1962b). The sequence of increase and decrease in organ size is reversed when a beetle prepares to fly to another tree and start a second egg gallery.

The female aggregating pheromone, *trans*-verbenol (Pitman and others 1968), is synergized by a small amount of another pheromone, *exo*-brevicomin (Rudinsky and others 1974). *Trans*-verbenol is an oxidation product of alpha-pinene, one of the terpenes found in small quantity in lodgepole pine. The pheromones, in conjunction with terpenes from the tree, guide other beetles to the tree and serve as a signal for mass invasion of the host (Vité and Pitman 1968). The observation that pheromone release can occur prior to initiation of feeding on the tree led to the hypothesis that females naturally release pheromones in response to stimuli from other females on the same tree (Rudinsky and others 1974). Terpenes in lodgepole pine consists mostly of beta-phellandrene, with small amounts of alpha-pinene, beta-pinene, 3-carene, myrcene, and camphene (Smith 1964). The proportions of these terpenes differ according to geographical location (Smith 1964; Lotan and Joye 1970; Shrimpton 1974). The terpene of particular interest is alpha-pinene, because it rapidly initiates and increases the bicsynthesis of *trans*-verbenol by mountain pine beetles (Hughes 1973).

Although a combination of *trans*-verbenol and alpha-pinene was most attractive to mountain pine beetles from western white pine (Pitman and Vité 1969), a combination of *trans*-verbenol and myrcene or terpinolene was considered more attractive to beetles in ponderosa pine (Billings and others 1976). The large amount of beta-phellandrene, and particularly its increase with diameter and phloem thickness in lodgepole pine, suggests that this terpene in combination with *trans*-verbenol may prove to be the most attractive to mountain pine beetles in lodgepole pine (Cole and others 1981).

If a tree is mass attacked (that is, attacked by many beetles within a day or two), pitch ceases to flow from holes where beetles have entered the bark, thus insuring success of beetle reproduction in the tree. Evidence of beetle infestation usually consists of pitch tubes where beetles have entered the tree and boring dust in cracks and at the base of the tree. Some trees have few pitch tubes because of rapid mass attack. Although pitch tubes may be absent or small, orangish-brown boring dust around the base of the tree is a sure sign that the tree has been invaded by a sufficient number of beetles to kill the tree. The size of pitch tubes is dependent upon the number and rate of beetle attacks and amount of moisture available to the tree. Physiological processes by which lodgepole pine resists mountain pine beetle infestation have been described by Shrimpton (1978).

Trees not mass attacked within 48 hours of initial attack were not successfully attacked that year (Rasmussen 1974). This is probably due to lack of sufficient beetles to generate a mass attack, or perhaps the quantity of terpenes and/or beetle pheromones may not be competitive with surrounding sources of attractants. Female beetles in many trees that were not mass attacked abandoned their galleries (Amman 1975a, 1980). Most females abandoned their galleries after constructing up to 2 inches (5 cm) of egg gallery. However, in these same trees, some females constructed gallery and oviposited regardless of the number of attacks on the tree. One notable extreme was a single attack on a tree with construction of 7 inches (17.8 cm) of gallery and oviposition throughout. However, resinosis as described by Reid and others (1967) would prevent egg hatch and/or larval development.

The average height of initial attack is 4.7 ft (1.4 m) (Rasmussen 1974). Initial attacks occurred between 4 and 6.9 ft (1.2 and 2.1 m) above ground level 79 percent of the time, and between 4 and 7.9 ft (1.2 and 2.4 m) 93 percent of the time. The remaining initial attacks occurred below the 4-ft (1.2-m) level. Succeeding attacks spread up, down, and around the bole.

Attack density did not change with height in trees in northern Utah and northwestern Wyoming (Carlson and Cole 1965); however, fewer attacks occurred with increased height in British Columbia (Shepherd 1965). Density of attacks increased with tree diameter (Carlson and Cole 1965). The length of the bole that is infested is partially related to both size of the beetle population and to tree diameter. Most trees 8 to 9 inches (20 to 23 cm) diameter at breast height (d.b.h.) are infested to a height of about 20 ft (6 m) or less, compared to an infested height of 30 to 40 ft (9 to 12 m) for trees 20 inches (51 cm) d.b.h. and larger (Cahill 1960). Differences in infested height occur between areas, with trees on the best sites being infested to a greater height.[4] This difference is related to the greater bole length on good sites. Klein and others (1978) noted that as an outbreak subsides there is a decline in infested height, which probably is related to lower beetle density since beetles attack the base first and then proceed to attack higher.

The number of attacks on the tree differs significantly with respect to cardinal direction, with the greatest density on the north aspect (Reid 1963). During a 2-year study, Rasmussen (1974) recorded 36 percent of initial attacks on the north aspect, 25 percent on the west, 21 percent on the east, and 18 percent on the south. Total attacks were distributed similarly to that of initial attacks. North aspects received the most, east and west aspects had intermediate numbers of attacks, and the south aspect had the least (Shepherd 1965). The distribution of attacks by aspect suggests beetles prefer cooler temperatures. Maximum bark surface temperatures on the north side of the tree were 1.8° F (1° C) cooler than air temperatures, whereas on the south side they were 11° F (6° C) higher than air temperatures (Powell 1967). Light may also influence attack behavior by aspect because beetles that are ready to initiate galleries are negatively phototactic (Schonherr 1971). In addition, the adult reverses its photopositive response at temperatures between 95° and 99.5° F (35° and 37.5° C) and becomes photonegative (Shepherd 1966).

Density of attacks is greater on rough than on smooth bark (Shepherd 1965; Safranyik and Vithayasai 1971). The number of niches available to females for starting galleries may influence attack density (Safranyik and Vithayasai 1971). Pheromones and tree vigor are also important factors. Attack density on individual trees is regulated by host condition (oleoresin and exudation) (Renwick and Vité 1970). Attacks stop when the tree no longer exudes resin at the sites of attack. Differences in attack densities on lodgepole pine trees of different size in any given year suggest that host condition is a factor in lodgepole pine, with the most vigorous trees attacked heaviest (Carlson and Cole 1965; Cole and others 1976). The work of Rudinsky and others (1974) indicates that antiaggregative pheromones, *exo*-brevicomin and *endo*-brevicomin, are involved in regulating attack densities. The amount and rapidity with which pheromones are produced are probably related to the sex ratio of the attacking population. Cole and others (1976) hypothesized that the change in attack density over the life of an infestation is related to sex ratio of the population.

Sex ratio differs among mountain pine beetle broods, but is almost always in favor of females. Any factor that stresses the population reduces male survival. Reduced male survival has been attributed to crowding (W. Cole 1973), to length of cold storage (Safranyik 1976; Watson 1971), and to thin phloem (Amman and Pace 1976) in laboratory studies; and to drying (Amman and Rasmussen 1974) or a combination of drying and thin phloem (Cole and others 1976) in field studies.

In laboratory studies, some broods consist entirely of females. This phenomenon raises the possibility of differential survival of X and Y sperm. Another possible consideration is the presence of a lethal cytoplasmic factor that causes death of the males during embryonic development (Lanier and Oliver 1966; Lanier and Wood 1968).

[4] Johnson, Philip C. Height of broods as a factor affecting the treatment of standing lodgepole pine trees infested by the mountain pine beetle. Coeur d'Alene, ID: U.S. Department of Agriculture, Agricultural Research Service, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory; 1951. 8 p. Unpublished report.

Sex ratios of beetle populations change somewhat from year to year as a result of population stress. Sex ratio shows a fairly strong association to tree diameter (Cole and others 1976) and changes by year of infestation (fig. 16).

During the initial years of an infestation, there was either no relation to tree diameter or only a slight tendency for small diameter trees to produce fewer females than large trees. For example, in 1970, beetles from 6-inch (15-cm) trees averaged 63 percent female compared to 70 percent female from 20-inch (50-cm) trees. However, as the infestation progressed, small diameter trees produced higher percentages of females than did large trees. In fact, during the middle years of the infestation, large diameter trees produced more males than early or late in the infestation. For example, at the height of the infestation (1975), brood from 6-inch (15 cm) d.b.h. trees averaged 85 percent female, compared to only 55 percent female from 20-inch (50-cm) d.b.h. trees (fig. 17).

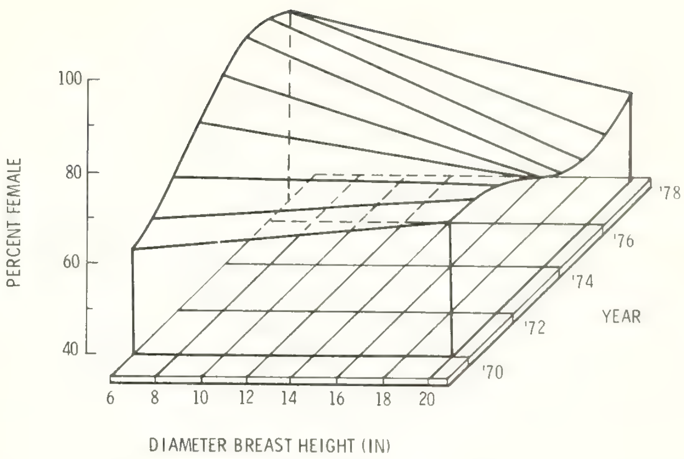

Figure 16.—Percent female in mountain pine beetle populations differed by diameter of lodgepole pine and year of infestation, Wasatch-Cache National Forest, Utah.

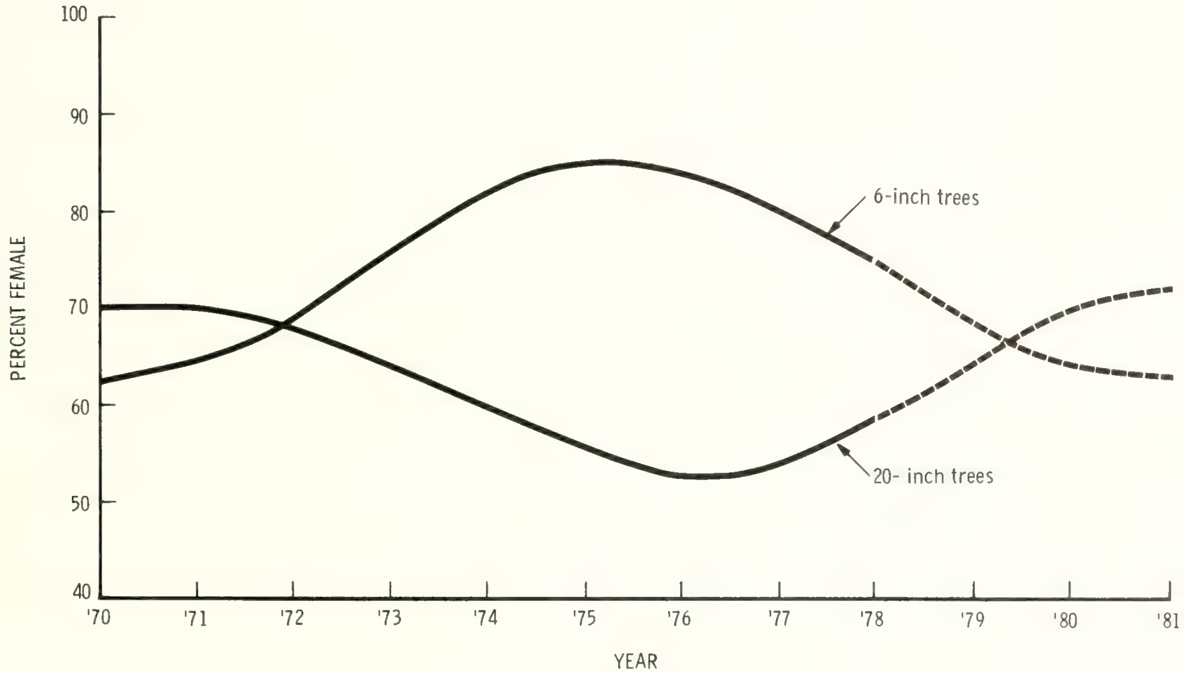

Figure 17.—Change in percent female of mountain pine beetle populations for the two extremes in lodgepole pine diameter classes during the life of an infestation, Wasatch-Cache National Forest, Utah.

An increase in the proportion of females emerging from small trees appears to occur almost from the beginning of the infestation. This suggests that conditions within the small trees are at their best at this time for male survival. As the infestation progresses, gallery density increases; thus intraspecific competition increases and, in addition, drying as a result of increased beetle activity under the bark increases. These factors are adverse to male survival and shift the sex ratio in favor of females. However, the decline in the proportion of females emerging from small trees toward the end of the infestation is difficult to explain. Conditions associated with less egg gallery possibly are beginning to shift more toward those that existed at the beginning of the infestation.

In the large diameter trees, survival may be impeded by the light gallery densities and conditions associated with them; for example, more resinous conditions in the phloem at the beginning of the infestation. In addition, the benefit of close association of larvae observed by W. Cole (1973) in laboratory rearings may be missing. As the infestation progresses and gallery density increases, conditions for survival of males apparently improve. Following the peak of the infestation, gallery density continues to increase, resulting in increased intraspecific competition and drying due to excessive amounts of egg gallery and to opening of the bark by large numbers of feeding larvae. These factors are adverse to male survival, resulting in the sex ratio shifting more toward females.

Because of the shift in sex ratio in field populations after the year of peak emergence, insufficient males probably exist to mate most females in a relatively short time. Hence, unmated females continue to produce the aggregative pheromone that attracts additional females and increases attack density. Attacks probably stop when enough males arrive to produce sufficient concentration of the antiaggregative pheromones. Therefore, the mountain pine beetle appears to regulate attack density by the pheromone system (Rudinsky and others 1974), but the differences noted in attack density among trees of different diameter appear to be related to host condition (Renwick and Vité 1970).

The strip attack is another strategy that helps the mountain pine beetle survive when their numbers are low. Only a strip of bark on a portion of the tree trunk is infested without killing the tree. These strips can contain extremely high brood production. For example, the central portion of a strip attack involving less than 25 percent of the circumference of a 16-inch (41-cm) d.b.h. lodgepole on the Wasatch-Cache National Forest had 180 brood emergence holes/ft^2 (930 cm^2) of bark surface. Egg gallery and larval mines along the edges of strip attacks are inundated with resin, and no brood survives. The bark from strip attacks eventually sloughs off, leaving the egg gallery etchings exposed on the sapwood surface. Previous mountain pine beetle infestations can be dated by comparing tree age with age of the strip attack.

In addition to the effect of attacking beetles on the tree, blue-stain fungi (*Ceratocystis montia* [Rumbold 1941] and *Europhium clavigerum* [Robinson-Jeffrey and Davidson 1968]) introduced by adult beetles play an important role in causing tree death (Safranyik and others 1975). Fungal spores, which are picked up during maturation feeding by new adults prior to leaving the tree, are carried in a maxillary mycangium (Whitney and Farris 1970). This association suggests a true symbiosis. Spores are introduced into a live tree as beetles attack and start constructing egg galleries. Blue-stain fungi invade the phloem, and especially the sapwood, where they help to reduce resin flow and disrupt the vascular system (Nelson 1934). An initial rapid reduction in moisture occurs in the sapwood (Reid 1961). Therefore, one benefit to the beetle appears to be regulation of moisture in the tree during beetle development. Blue-stain fungi do not appear to be necessary to mountain pine beetle nutrition (Whitney 1971).

Mating and Oviposition

Almost all mating occurs after the female starts her egg gallery. Less than 1 percent of females were mated in lodgepole pine prior to emergence (Reid 1958a). Only 2 percent of the females removed from ponderosa pine bark prior to emergence contained spermatozoa (McCambridge 1970). In males, quantity of mature spermatozoa increases within vasa deferentia and vasa efferentia for several days following emergence and mating (Cerezke 1964).

After the female starts an egg gallery she usually is soon joined by a male. Acoustic signals are an important part of attack and mating behavior. Males stridulate prior to entering the gallery. Several reasons for this have been proposed. Both attractant and stress stridulations were identified (Michael and Rudinsky 1972). Stridulation stopped production of aggregation pheromone by the Douglas-fir beetle, *D. pseudotsugae* Hopkins (Rudinsky 1968). In addition, stridulation may be part of territorial behavior by discouraging males from entering occupied territory, thus distributing the frequently scarce male population more efficiently (McGhehey 1968). Male stridulation also notifies the female that a male and not a female is entering her gallery (Ryker and Rudinsky 1976). Females usually repel other females that attempt to enter their galleries.

Beetles may mate at the entrance or within the gallery. Within the gallery, males and females turn in opposite directions with abdomens towards each other, male posterior to the female (Reid 1958a). An average of 11 minutes elapsed from male-female contact until copulation, which lasted 3.5 to 5 minutes (Ryker and Rudinsky 1976). Copulation may occur several times during egg gallery construction (Reid 1958a). After copulation, the male may either leave the gallery and seek another female to mate, or he may stay in the gallery with the female. Should the male stay, he pushes boring dust (that the female chews away in the process of making the gallery) and resin out of or into the bottom of the gallery. The boring dust plug packed in the entrance of the gallery probably prevents other mountain pine beetles and enemies from entering. If a male gets in the way of the female, she kills him and packs him along with the boring dust into the bottom of the gallery. Mated females elongate their egg galleries at a rate faster than unmated females, presumably because of assistance by the male (if he stays) in moving and packing boring dust (fig. 18) (Amman 1980; Reid 1958a; Rasmussen 1974). The female usually cuts horizontally or obliquely across the grain of the wood for about 0.25 inch (6 mm) when she initates the gallery, then tunnels upward through the phloem and the outer surface of the sapwood, following the grain of the wood even when it is spiral-grained. This behavior, coupled with the original spacing of galleries, does much to reduce intraspecific competition among the developing brood.

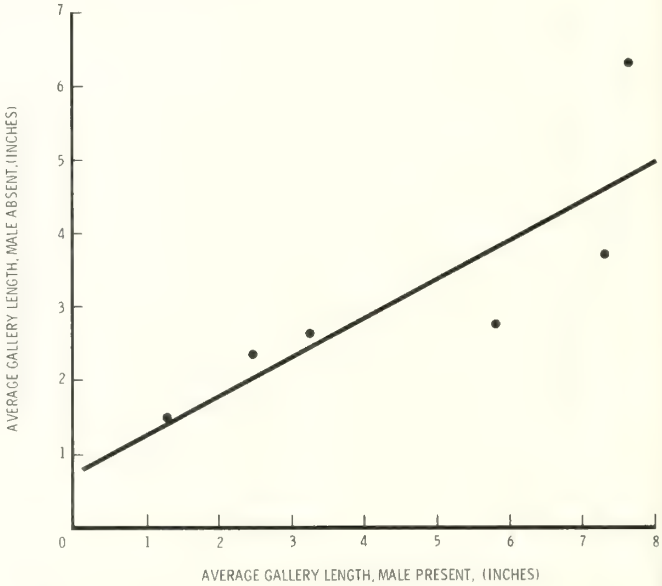

Figure 18.—Average lengths for mountain pine beetle galleries that contained males, compared to those that did not contain males (only those plots were used that had both categories represented) (Amman 1980).

Ventilation tunnels are placed at irregular intervals along the egg gallery. These extend from the egg gallery to near the outer surface of the bark and appear related to stage of gallery construction, thickness of bark, and beetle activity (Wood 1963). In thin-barked lodgepole pine, 18 of 35 egg galleries contained ventilation chambers, and only 3 had more than 1 chamber (Wood 1963).

Eggs are laid in individual niches cut in the phloem in groups that alternate irregularly between the two sides of the gallery. The average number of eggs laid in an inch of gallery ranges between 4.2 and 5.9 (1.7 and 2.3/cm). However, as many as 15 eggs/inch (5.9/cm) have been laid (Amman 1972a; Reid 1962b). More than 200 eggs were deposited in some individual galleries that were more than 50 inches (127 cm) long (Reid 1962b). Heavy egg production occurs during early gallery construction, then gradually declines (fig. 19). Several factors affect oviposition. Oviposition differs with the proximity of adjacent egg galleries. The average number of eggs laid on sides of adjacent galleries ranged from 1.7/inch (0.7/cm) for galleries spaced 0.12 inch (3 mm) apart to 3.6/inch (1.4/cm) for galleries spaced 0.88 inch (21 mm) apart (fig. 20). Oviposition reaches a plateau where galleries are 1 inch (25 mm) apart. Therefore, the activities of adjacent parent beetles would have little effect at distances greater than 1 inch when females are boring simultaneously. Stridulation by females probably serves a territorial function (Rudinsky and Michael 1973) and helps to maintain distance between galleries or causes reduced oviposition. However, when one beetle bores ahead of its neighbor, previous gallery construction might be sensed from drying of phloem and presence of fungi, bacteria, and yeasts, and thus the beetle reduces oviposition.

Large beetles lay more eggs than small beetles (Amman 1973; McGhehey 1971; Reid 1962b). The average number of eggs laid per inch of gallery ranged from 3.2 (1.3/cm) for a beetle 0.17 inch (4.3 mm) long to 7.9 (3.1/cm) for a beetle 0.21 inch (5.4 mm) long (fig. 21). The average number of eggs laid per day ranged from 3.4 for a beetle 0.17 inch (4.3 mm) long to 8.2 for a beetle 0.23 inch (5.9 mm) long (fig. 21). Although these differences are significant, much variation in egg-laying capacity exists among beetles of a similar size, even when they are held under similar conditions of food, temperature, and egg-laying substrate. Average length of gallery constructed per day also was significantly related to beetle length.

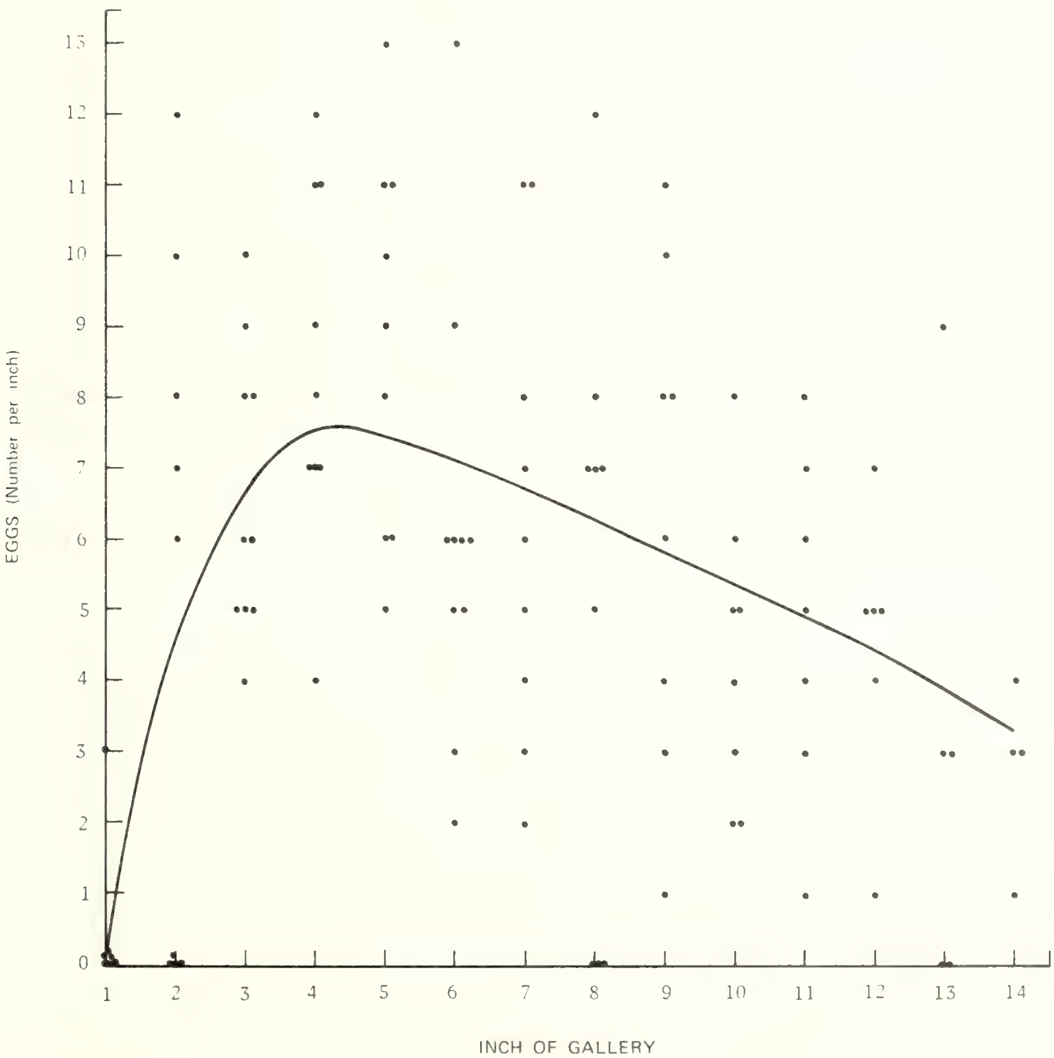

Figure 19.—Numbers of mountain pine beetle eggs laid per inch of gallery (46 galleries 6-14 inches [15-36 cm] long). (See regression statistics in appendix.)

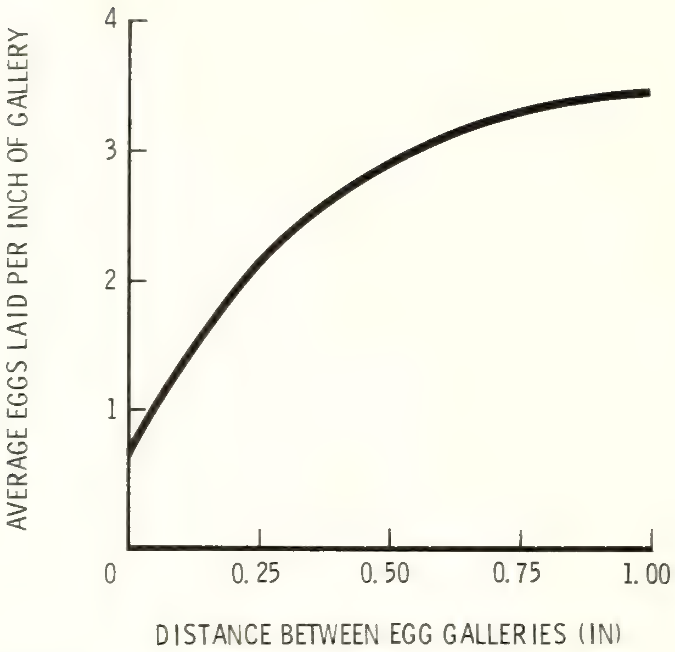

Figure 20.—Average number of eggs laid per inch of egg gallery in relation to distance between galleries.

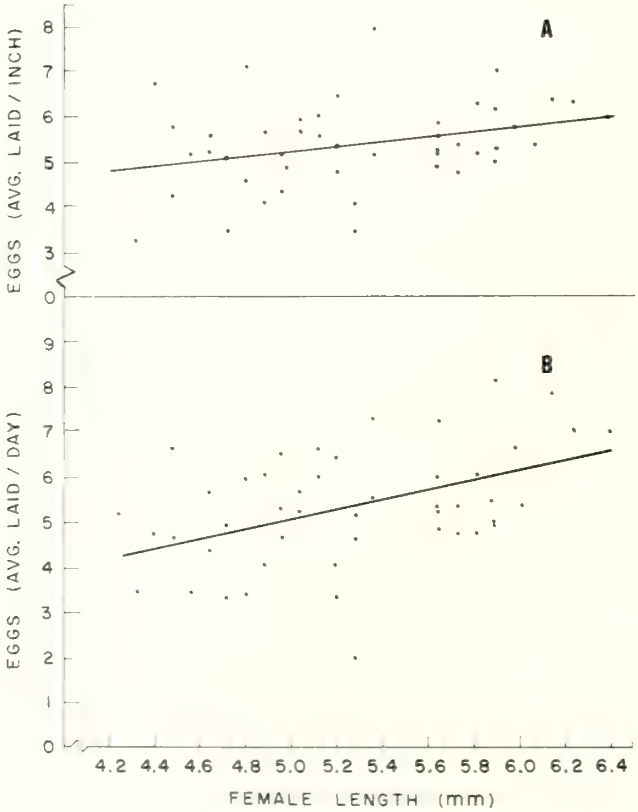

Figure 21.—The relation of oviposition behavior to length of female mountain pine beetle. (See regression statistics in appendix.)

Oviposition differed in relation to phloem thickness, with greater numbers of eggs laid in thick than in thin phloem (fig. 22). The average number of eggs ranged from 3.5/inch (1.4/cm) in phloem 0.06 inch (1.5 mm) thick to 9.6/inch (3.8/cm) in phloem 0.18 inch (4.6 mm) thick. Average number of eggs laid per day ranged from 1.7 in phloem 0.06 inch (1.5 mm) thick to 7.7 in phloem 0.20 inch (5.1 mm) thick. The relation between rate of gallery construction and phloem thickness was not significant. This is surprising because a beetle in thin phloem constructs more of its gallery in the sapwood (which should be harder to chew) than a beetle in thick phloem. Average depth of excavation into the sapwood ranged from 0.045 inch (1.1 mm) in phloem 0.04 inch (1.0 mm) thick to 0.01 inch (2.8 mm) where phloem was thicker than 0.12 inch (2.8 mm). A possible explanation for differences in rates of oviposition and numbers of eggs laid between thin and thick phloem might be related to lower nutritional quality of thin phloem. Another explanation is that beetles expended more energy in constructing galleries where they chewed deep into the sapwood, thus leaving less energy for egg production.

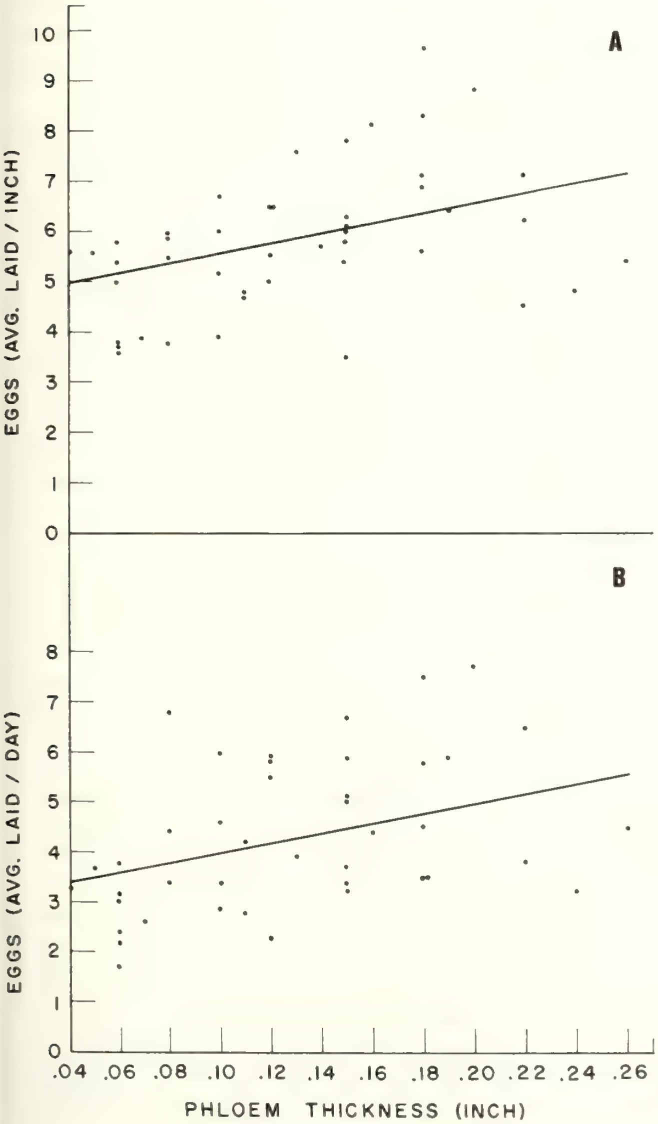

Figure 22.—The relation of oviposition behavior of the mountain pine beetle to thickness of lodgepole pine phloem. (See regression statistics in appendix.)

Both rate of gallery construction and number of eggs laid are strongly related to temperature (fig. 23). Some oviposition occurs as low as 35° F (1.7° C) (Reid 1962b). However, both functions increase substantially when temperatures exceed 59° F (15° C) (Amman 1972a). Average number of eggs laid per inch of gallery ranged from 1.3 (0.5/cm) at 44.6° F (7° C), to 8.3 (3.3/cm) at 59° F (15° C). The number of eggs laid per day ranged from an average of 0.23 at 44.6° F (7° C) to 6.6 at 68° F (20° C). A curvilinear relation is indicated, with a big increase in oviposition occurring at 68° F (20° C). Peak oviposition is almost reached at 68° F (20° C); consequently, numbers of eggs would not be expected to increase significantly at higher temperatures. However, the curves for both length of gallery constructed per day and number of eggs deposited per day continue to rise and could be expected to peak at temperatures higher then 68° F (20° C).

Crowding during larval development affected oviposition by the resultant new adults (Cole 1973). Adults very crowded as larvae laid fewer eggs and constructed fewer inches of gallery than adults much less crowded as larvae. Likewise, adults crowded at medium levels as larvae laid fewer eggs than adults least crowded as larvae.

Egg Hatch

Embryonating eggs were classified into four stages of development. Stage I eggs were homogeneously opaque in appearance. Stage II eggs were clear at one end. Stage III eggs were clear at both ends. And stage IV eggs possessed a clearly defined head capsule (Reid and Gates 1970).

Several factors are important to egg hatch. Reid and Gates (1970) established 40° F (4.4° C) as minimum and about 95° F (35° C) as maximum temperatures at which eggs could hatch. An average of 5,113 degree-hours (a degree-hour is 1 degree of temperature sustained for 1 hour above the threshold of development) above 40° F (2,841 degree-hours above 4.4° C) was required for 50 percent of eggs to hatch under field conditions. Optimum temperatures for hatch in the laboratory range from 69° to 77° F (21° to 25° C) (Reid and Gates 1970). We observed that hatching occurred between 36.6 days at a constant 50° F (10° C) and 8.4 days at a constant 68° F (20° C), the range of temperatures used (fig. 24).

In addition to suitable temperature, 90 percent or greater relative humidity is required for successful embryogenesis and hatch (Reid 1969). Egg survival was only slightly affected by resin vapors (3 percent mortality), but an envelope of resin caused almost complete mortality (Reid and Gates 1970). Mortality was about 40 percent when eggs were only half covered by resin.

Larval Behavior and Development

After hatching, larvae feed individually in the inner bark (phloem). Larval galleries usually extend at right angles from the egg galleries of the parents. Consequently, feeding larvae eventually girdle the tree.

W. Cole (1973) studied larval behavior under several levels of crowding in an artificial medium. He found that initial feeding and survival rates of larvae increased as crowding increased. Also, he noted that stadial length (duration between molts) decreased with increased crowding during the first and second stadia, but increased during the third and fourth stadia. Decreased survival to the adult stage occurred with prolonged crowding at high levels.

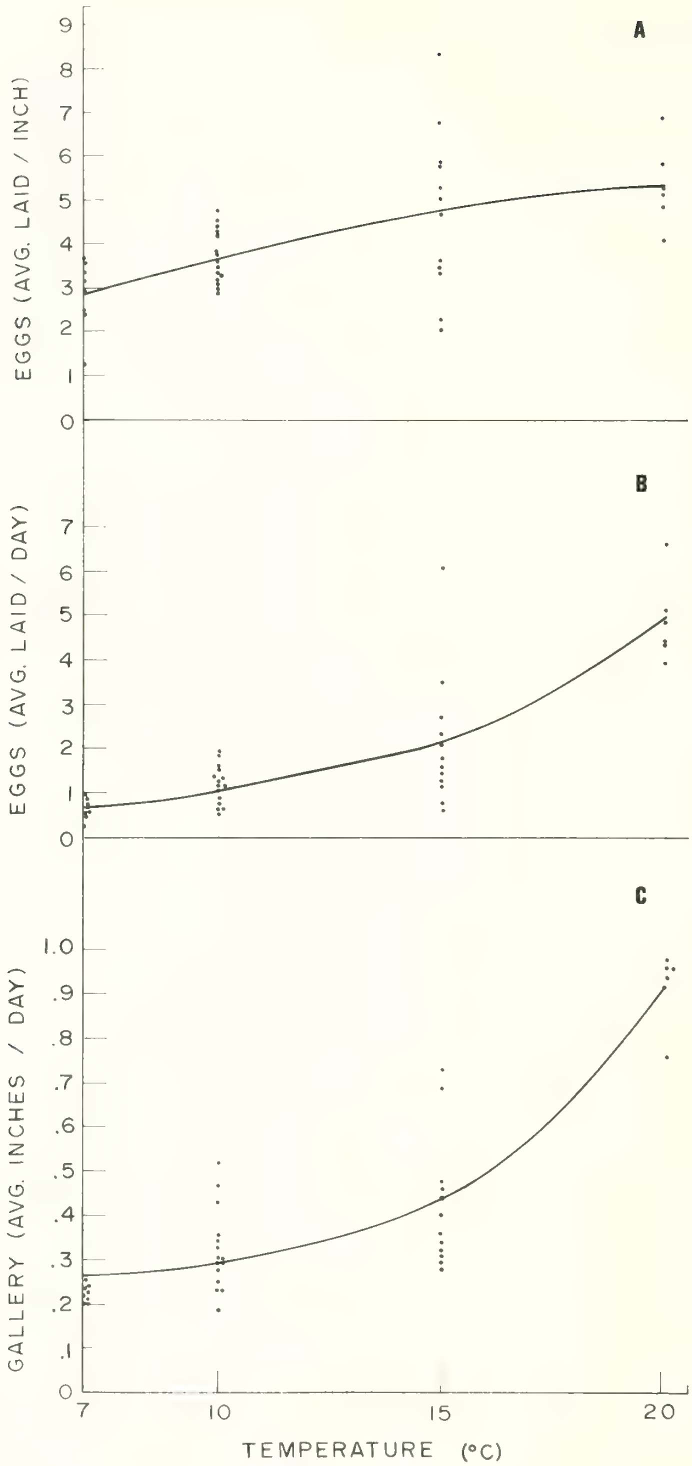

Figure 23.—The relation of oviposition behavior of the mountain pine beetle to temperature. (See regression statistics in appendix.)

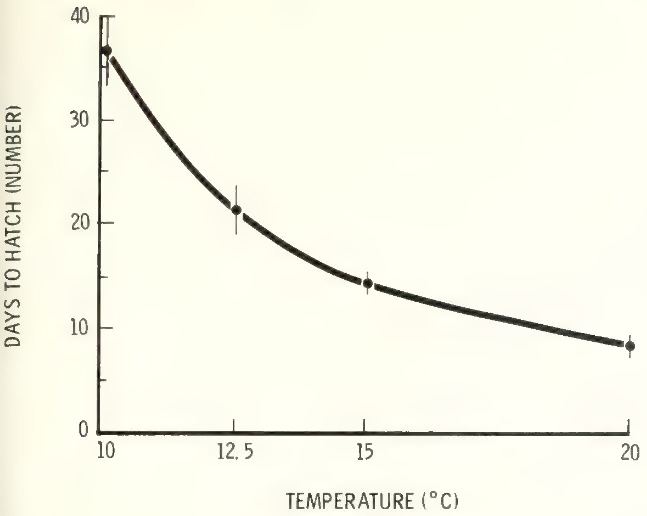

Figure 24.—Average number of days for mountain pine beetle eggs to hatch at different constant temperatures. Vertical line through each data point represents ± one standard deviation.

Larval behavior differs in thick and thin phloem. In thick phloem, a double layer of larvae may occur while larvae are small. Some feed near the surface of the sapwood, whereas the remainder near the inner surface of the dead outer bark. This behavior initially reduces competition for food and space.

In both thick and thin phloem when larval mines and egg galleries are encountered, some larvae may cross them while other larvae may mine toward the egg gallery. Still others submerge into the phloem to mine under galleries. Larvae do not necessarily keep extending their mines away from the parent egg gallery. Some back down their mines, then commence to feed again and fill the area behind them with boring dust. Others feed along the edges of their mines, making the mines three to four times the width of the larva and up to 0.5 inch (1.27 cm) long.

Larvae in thin phloem mined faster than those in thick phloem for the first 2 weeks ($P < 0.02$), but at the end of the third week, galleries were of similar length ($P > 0.05$) (fig. 25a). The close proximity of larvae in thin phloem may have stimulated more rapid feeding (W. Cole 1973) than in thick phloem where two layers of larvae may occur. Possible nutritional differences between thick and thin phloem would influence larval feeding rate. Larvae in thin phloem possibly needed to mine farther to obtain the same nutritional requirements acquired with a short gallery in thick phloem. The increased feeding rate by large larvae in thick phloem may disperse larvae before pupation. Physical encounters among larvae frequently result in death either by cannibalism or entomocide, which W. Cole (1973) defines as killing of one larva by another but not necessarily for food as with cannibalism. Dispersion of larvae prior to pupation would reduce the chances of pupae being cannibalized by late developing larvae, and would reduce competition for food by new adults during maturation feeding when they consume up to 0.5 inch² (1.6 cm²) of phloem each during maturation feeding prior to flight.

As expected, first instars in both thin and thick phloem were the same size. However, larvae feeding in thin phloem had significantly wider head capsules during the second and third instars than larvae in thick phloem ($P < 0.001$), but fourth instars from thick phloem had larger head capsules than larvae in thin phloem ($P < 0.001$) (fig. 25b). The larger second and third instars in thin phloem may be related to close association and faster feeding rate of larvae (indicated by longer larval mines) (W. Cole 1973). The larger size of fourth instars in thick phloem may be related to better overall nutrition and an appar-

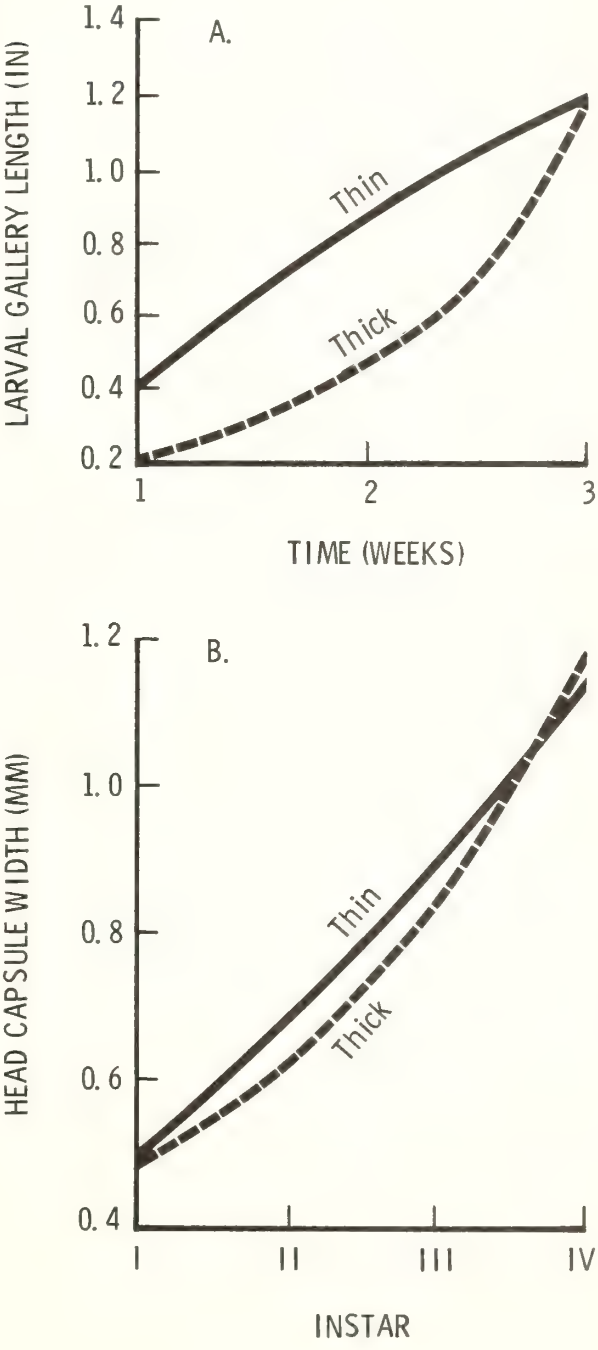

Figure 25.—A. Rate of larval gallery construction in thin and thick phloem; B. head capsule width of larvae reared in thin and thick phloem.

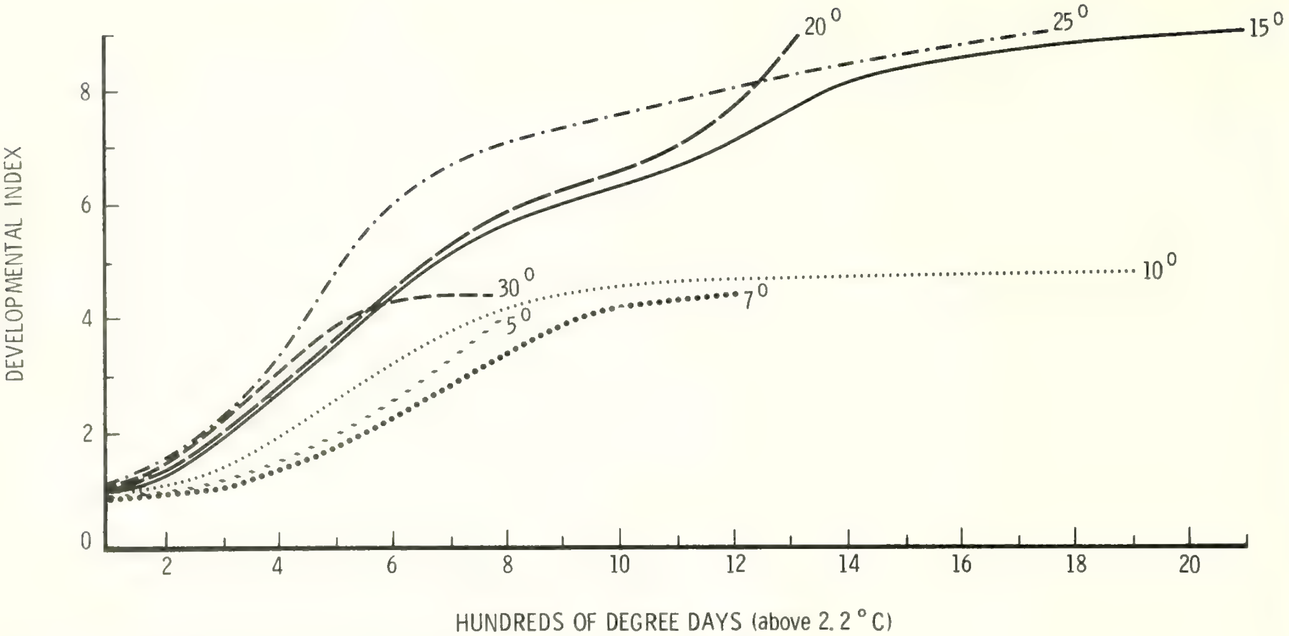

Figure 26.—Mountain pine beetle development at seven constant temperatures. Developmental Index: 1 = egg; 2–5 = I-IV larval instars; 6 = pupa; 7 = teneral adult; 8 = new adult; 9 = new emerged adult.

ent rapid feeding rate (or mining rate) in this instar. Adults from larvae feeding in thick phloem were significantly larger than those resulting from larvae feeding in thin phloem, as previously noted by Amman and Pace (1976).

Beetle development from egg to teneral adult required about 626 degree-days (a degree-day is 1 degree above the threshold for 24 hours) above 50° F (348 degree-days above 10° C) threshold in the subcortical zone of the tree (Powell 1967), and about 500 degree-days above 50° F (278 degree-days above 10° C) air temperature (Reid 1962a). We found the beetle required about 675 degree-days above 50° F (375 degree-days above 10° C) to reach the teneral adult stage at a constant 59° F (15° C), our lowest temperature at which development was completed. Degree-days required for development at 59° F (15° C) approximates the estimate given for the subcortical region by Powell (1967). Beetle rearing was unsuccessful at 59° F (15° C) at Victoria (L. Safranyik, Canadian Forestry Service, Victoria, B.C., personal communication, May 5, 1981), suggesting differences in beetle subpopulations.

In laboratory studies, the threshold for larval development is near 36° F (2.2° C) (McCambridge 1974). Growth rate increases with temperature from 40° to 55° F (4.4° to 12.8° C) and was similar at each test temperature regardless of individual larval size (McCambridge 1974).

We conducted studies on rate of beetle development at constant temperatures from 41° to 86° F (5° to 30° C). The rate of development was very slow at temperatures of 41° and 44.6° F (5° and 7° C), but much of this was attributed to very slow egg development. Even though the slabs were held at room temperature of 76° F (24.4° C) for 8 days and received 320 degree-days above 36° F threshold (178 degree-days above 2.2° C), an additional 250 and 427 degree-days above 36° F (139 and 237 degree-days above 2.2° C) at 41° and 44.6° F (5° and 7° C), respectively, were required before larvae were first detected.

The apparent greater heat requirements at 44.6° F (7° C) than 41° F (5° C) are an artifact probably related to time of initial oviposition. First and second instars seem to develop moderately fast at these low temperatures. However, development begins to slow when larvae reach the third instar (fig. 26). Development of third instars is slower than in earlier instars, even at 50° F (10° C). Slowing of development is even more pronounced in the fourth instar at these low temperatures, and pupation requires more degree-days (or possibly a much higher threshold temperature) than for temperatures exceeding 50° F (10° C). It appears that the threshold for pupation is near 50° F (10° C).

Larval growth is not linear at temperatures below 59° F (15° C) (fig. 26). Higher temperatures are required to maintain the growth rate of earlier instars, and apparently a higher threshold temperature is needed for development to proceed to the next stage. Only 11 percent of larvae held at 50° F (10° C) reached the pupal stage after 2,245 degree-days above 36° F (2.2° C) threshold, whereas beetles held at 59° F (15° C) contained 14 percent pupae after only 819 degree-days. Overall development was most efficient (required the fewest degree-days) at 68° F (20° C), with some beetles completing development and emerging after 895 degree-days above 36° F (2.2° C) threshold. Slightly more degree-days were required at 59° and 77° F (15° and 25° C)—1,150 and 1,300 respectively—before emergence. Both temperatures appear somewhat inhibitory to later stages beginning with the pupa at 50° F (10° C) and teneral adult at 77° F (25° C). At a constant 86° F (30° C), beetles died before completing the pupal stage.

Certain advantages accrue to the mountain pine beetle because of the greater heat requirements of advanced stages. First, in the fall the greater heat requirements prevent most beetles from progressing to the pupal and teneral adult stages, which are highly susceptible to winter killing by cold temperatures (Amman 1973; Reid 1963). Second, the greater heat re-

quirements (or higher threshold temperature for development) of late stages help to keep the population together by allowing late-hatching larvae to catch up in development. Synchrony is accomplished when the early instars keep developing after temperatures are too cool for development in later instars. Synchrony of the population is important if the beetles are to emerge en masse to infest and kill the largest, most vigorous trees in the forest.

When fully developed in late spring, larvae excavate oval cells in the bark (these may extend slightly into the sapwood) where they pupate and later become adults.

BEETLE SURVIVAL AND MORTALITY

Phloem Thickness Effect

The principal factor determining brood survival and production in lodgepole pine is quantity of phloem, the food of developing larvae (Amman 1969; 1972b). Phloem in a sample of lodgepole pines had accumulated for an average of 21.7 years (Cabrera 1978). Phloem thickness is positively correlated with tree diameter (Amman 1969) and to characteristics of good tree vigor (D. Cole 1973). Brood production of the mountain pine beetle was found to increase with total bark thickness (Amman 1969; Reid 1963). Phloem thickness was considered the causal factor (Amman 1969). Subsequent laboratory studies (Amman 1972b) and field studies (Berryman 1976) demonstrated brood production to be positively correlated with phloem thickness. In the laboratory, brood production ranged from an average of 23 beetles/ft² (930 cm²) for phloem 0.05 inch (1.27 mm) thick to an average of 138 beetles/ft² (930 cm²) for phloem 0.17 inch (4.32 mm) thick (fig. 27). Brood production also shows a positive increase with egg gallery length (Amman and Pace 1976) and number of attacks (Berryman 1976; Schmid 1972) forming an asymptote that extends out to the highest densities observed. This suggests that brood production will be governed by phloem quantity, regardless of intraspecific competition.

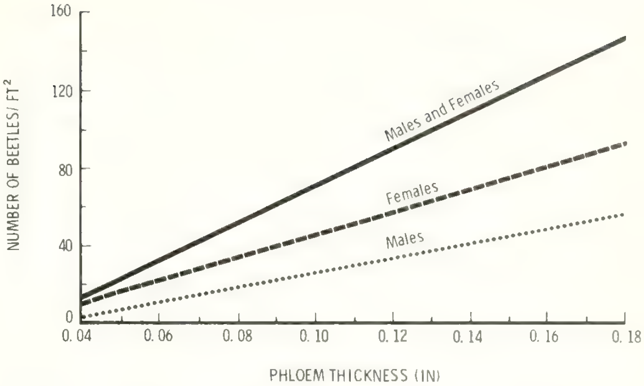

Figure 27.—Mountain pine beetle brood production in relation to phloem thickness of lodgepole pine. (See regression statistics in appendix.)

Phloem of young trees or younger portions of older trees (upper portions of the boles) has more and larger cortical resin ducts than that of older portions of trees (Berryman 1976). However, numbers and sizes of cortical resin ducts vary considerably (Cabrera 1978). As the number of resin ducts increases in the phloem, less food is available for larvae (Amman 1972b). Mountain pine beetles produce large numbers of new adults in phloem of young trees or younger portions of older trees in the laboratory (table 6). However, beetles don't do well in young trees in the field because of excessive drying following tree death (Cole and others 1976). Drying may be related to the interaction of the resinous bark of young trees and the blue-staining fungi that appear to be moisture regulators of the beetle-infested tree. Resin could adversely affect survival of the fungi (Shrimpton 1973) and its penetration into the sapwood (Ballard and others 1980) where the rate of transpiration and hence drying of the wood might be slowed.

Table 6.—Mountain pine beetle production, percent female and length in billets from different aged portions of three lodgepole pine trees 50-59 years old

	Age class							
	19-29 (n = 15)		30-39 (n = 20)		40-49 (n = 12)		50-59 (n = 13)	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Beetles/ft² (930 cm²)	162.34	28.94	172.45	34.14	156.51	35.35	174.32	30.95
Percent female	63.40	9.69	64.04	8.37	68.27	10.22	61.88	7.36
Beetle length (mm)								
Male	4.37	.09	4.34	.15	4.40	.13	4.39	.16
Female	4.96	.10	4.94	.09	4.99	.08	4.97	.08

Factors of Mortality

A mortality factor, in order to be effective, must cause a departure from expected survival and emergence as predicted from phloem thickness. The mortality factor then would either cause the infestation to decline with less overall tree killing or cause the rate of tree killing to slow. In the latter case, the eventual loss of trees could be about the same as where the mortality factor was not operating. An example is the effect of insecticide treatment of mountain pine beetles, which was shown to extend the length of the infestation in a case or two but did not save trees since tree losses were the same in treated and untreated stands (Amman and Baker 1972).

A variety of mortality factors affect mountain pine beetle populations, and their influence in several geographic areas was investigated during many years of life table sampling. Two earlier papers (Cole 1974, 1975) detailed portions of these investigations.

Parasites and predators.—A long list of parasites and predators of the mountain pine beetle has accumulated starting with DeLeon's (1934) study; a few additional ones have been added since then (table 7). The most numerous insect parasites and predators in lodgepole pine have been presented in a field key (Rasmussen 1976).

Table 7.—Parasites and predators of the mountain pine beetle; all species were reported by DeLeon (1934) unless otherwise noted

Class Insecta
- Order Hemiptera
  - Family Anthocoridae
    - Several species
- Order Coleoptera
  - Family Staphylinidae
    - *Nudobius* sp.
    - *Quedius longipennis* Mann.
  - Family Histeridae
    - *Isolomalus mancus* Csy.
    - *Platysoma punctigerum* Lec.
  - Family Cleridae
    - *Enoclerus lecontei* (Wolc.)
    - *Enoclerus sphegeus* (Fabr.)
    - *Thanasimus undatulus* Say.
  - Family Pythidae
    - *Pytho planus* Herbst.
  - Family Trogositidae
    - *Temnochila virescens* (Fab.) var. chlorodea (Mann.)
  - Family Nitidulidae
    - *Glischrochilus vittatus* (Say)
    - *Epirea linearis* Makl.
  - Family Rhizophagidae
    - *Rhizophagus procerus* Csy.
  - Family Cucujidae
    - *Cucujus clavipes* Fabr. var. *puniceus* Mann.
  - Family Colydiidae
    - *Lasconotus complex* Lec.
  - Family Tenebrionidae
    - *Corticeus parallelus* (Melsheimer)
    - *Corticeus substriatus* (LeConte) (Parker and Davis 1971)
- Order Diptera
  - Family Xylophagidae
    - *Xylophagus abdominalis* Loew.
  - Family Dolichopodidae
    - *Medetera aldrichii* Wheeler

Table 7—(con.)

  - Family Lonchaeidae
    - *Lonchaea viridana* Meigen
  - Family Asilidae
    - *Laphria gilva* (Linnaeus) (Schmid 1969)
- Order Hymenoptera
  - Family Braconidae
    - *Coeloides dendroctoni* Cush.
  - Family Pteromalidae
    - *Pachyceras eccoptogastri* Ratz.
    - *Dinotiscus* (= *Cecidostiba*) *dendroctoni* Ashm.
    - *Dinotiscus* (= *Cecidostiba*) *acutus* (Prov.)
    - *Dinotiscus burkei* (Crawford)
    - *Rhopalicus pulchripennis* Cwfd. (Dahlsten and Stephen 1974; Rasmussen 1976)
  - Family Eurytomidae
    - *Eurytoma cleri* Ashmead

Class Nematoda
  - Family Rhabditidae
    - *Aphelenchoides conurus* Steiner (Steiner 1932)
    - *Aphelenchoides acroposthion* Steiner (Steiner 1932)
    - *Contortylenchus reversus* (Thorne) (Thorne 1935)
    - *Mikoletzkya pinicola* (Thorne) (Thorne 1935; Reid 1958c)
    - *Cryptaphelenchus latus* (Thorne) (Thorne 1935)
    - *Ektaphelenchus tenuidens* (Thorne) (Thorne 1935; Reid 1958c)
    - *Panagrodontus dentatus* Thorne (Thorne 1935; Reid 1958c)
    - *Sphaerularia hastata* Khan (Reid 1958c)
    - *Aphelenchoides brachycephalus* Thorne (Reid 1958c)
    - *Aphelenchoides talonus* Thorne (Reid 1958c)

Class Aves
  - Family Caprimulgidae
    - prob. *Chordeiles minor* (Forster) (Rust[1])
  - Family Picidae
    - *Picoides tridactylus* (Linnaeus) (Rust[1])
    - *Picoides pubescens* (Linnaeus) (Amman 1973)
    - *Picoides villosus* (Linnaeus) (Rust[1])
  - Family Tyrannidae
    - *Contopus sordidulus* Sclater (Stallcup[2])
    - *Contopus borealis* (Swainson) (Stallcup[2])
    - *Empidonax* sp. (Stallcup[2])
  - Family Corvidae
    - *Nucifraga columbiana* (Wilson) (Stallcup[2])
  - Family Paridae
    - *Parus gambeli* Ridgeway (Stallcup[2])
  - Family Sittidae
    - *Sitta pygmaea* Vigors (Stallcup[2])
    - *Sitta carolinensis* Latham (Stallcup[2])
    - prob. *Sitta canadensis* Linnaeus (Blackman 1931; Rust[1])
  - Family Certhiidae
    - *Certhia americana* Bonaparte (Stallcup[2])
  - Family Muscicapidae
    - *Turdus migratorius* Linnaeus (Stallcup[2])
    - *Mydaestes townsendi* (Audubon) (Stallcup[2])
    - prob. *Sialia currucoides* (Bechstein) (Beal 1939; Blackman 1931)
  - Family Emberizidae
    - *Dendroica coronata* (Linnaeus) (Stallcup[2])

[1]See footnote 6 in text.
[2]See footnote 7 in text.

Egg parasites and predators were studied in the laboratory during four seasons. Egg mortality ranged between 2.5 and 6.5 percent for the four seasons (table 8). The greatest loss was attributed to nematodes (1.13 to 4.06 percent), which are known to have considerable influence on bark beetles (Massey 1966). *Mikoletzkya pinicola* (Thorne) was identified in pure culture (C. L. Massey, letter dated March 16, 1971) from our earlier beetle rearing studies. Loss to nematodes occurred somewhat evenly throughout the galleries (fig. 28). Unidentified fungi caused the second greatest loss of eggs (0.76 to 1.80 percent), with most usually occurring in the first few inches of the gallery (fig. 28). Other factors causing small egg losses were: cannibalism or entomocide by early hatching larvae (0.0 to 1.25 percent), unknown causes (0.0 to 0.31 percent), and infertility (0.18 to 0.89 percent). Unidentified mites accounted for only two eggs (0.06 percent) during one season. Most mites must have been saprophytic or fungus feeders, or were predacious on other organisms under the bark. Predatory mites of the mountain pine beetle were not found during a study of Colorado and South Dakota beetles (Boss and Thatcher 1970).

Although not included in the previous tests, *Medetera aldrichii* may destroy 40 to 50 percent of beetle eggs (DeLeon 1935b). Schmid (1971) reported *Medetera* larvae preyed on beetles eggs in the first few inches of egg gallery and consumed from 12 to 25 eggs each during 15 days of laboratory rearing.

The most important predator of mountain pine beetle larvae is *Medetera aldrichii* Wheeler (DeLeon 1935b). *Medetera* fed on almost any species of larva, including its own, and DeLeon (1935b) believed that cannibalism was important in reducing *Medetera* populations. However, in its favor, *Medetera* had no natural enemies of the immature forms, and it may feed on a pine beetle larva for only a short time, abandon the larva (which later dies), and then search for another prey (DeLeon 1935b). This predatory behavior greatly increases the number of prey destroyed per predator, compared to those predators consuming all of a prey before killing another. However, this behavior appears to be density dependent (Nagel and Fitzgerald 1975). When prey are scarce, *Medetera* consumes most of each prey before seeking another.

The most important parasite is a brachonid, *Coeloides dendroctoni* Cushman (DeLeon 1935a). *Coeloides* was considered tne most important natural enemy of the mountain pine beetle because most larvae parasitized by it were fully grown and almost ready to pupate. Bark beetle larvae that have reached this stage have a high probability of reaching the adult stage unless parasitized (DeLeon 1935a). *Medetera* was considered overall to be a less effective natural enemy than *Coeloides* because many of the beetle larvae that *Medetera* destroyed in the fall, when both predator and prey were most abundant, would have died from other causes before maturing.

Laboratory studies of some insect predators have established their potential effect on beetle numbers. Each *Enoclerus sphegeus* Fabricius adult killed one mountain pine beetle adult per day (Schmid 1970a). *Enoclerus sphegeus* larvae consumed an average of 16 large or 38 small mountain pine beetle larvae while completing development (Amman 1970). Larvae of another clerid, *Thanasimus undatulus* Say, consumed an average of 18 large or 35 small mountain pine beetle larvae to complete development (Amman 1972c). Completion of larval development by *Medetera* required an average of 14.7 Douglas-fir beetle larvae (*D. pseudotsugae* Hopkins), but only 6.2 when fed exclusively large larvae (Nagel and Fitzgerald 1975).

Attempts have been made to evaluate the impact of parasites and predators on mountain pine beetle populations in the field. Bedard[5] found that 54 percent of the brood in windfelled trees were parasitized, and that parasitism averaged 65 percent in standing trees. He recommended against chemical treatment of

Table 8.—Mountain pine beetle egg mortality by specific factors and infertility, Wasatch-Cache National Forest, Utah

Year	Eggs examined	Mortality factors: Nematodes	Fungi	Entomocide	Mites	Unknown	Infertile	Total egg loss
	No.	*Percent*						
1972	2,093	4.06	0.76	1.25	0.00	0.05	0.38	6.50
1974	3,581	2.85	1.51	.06	.06	.31	.89	5.68
1975	3,563	1.23	1.80	.00	.00	.00	.87	3.90
1976	3,811	1.13	1.13	.00	.00	.08	.18	2.52

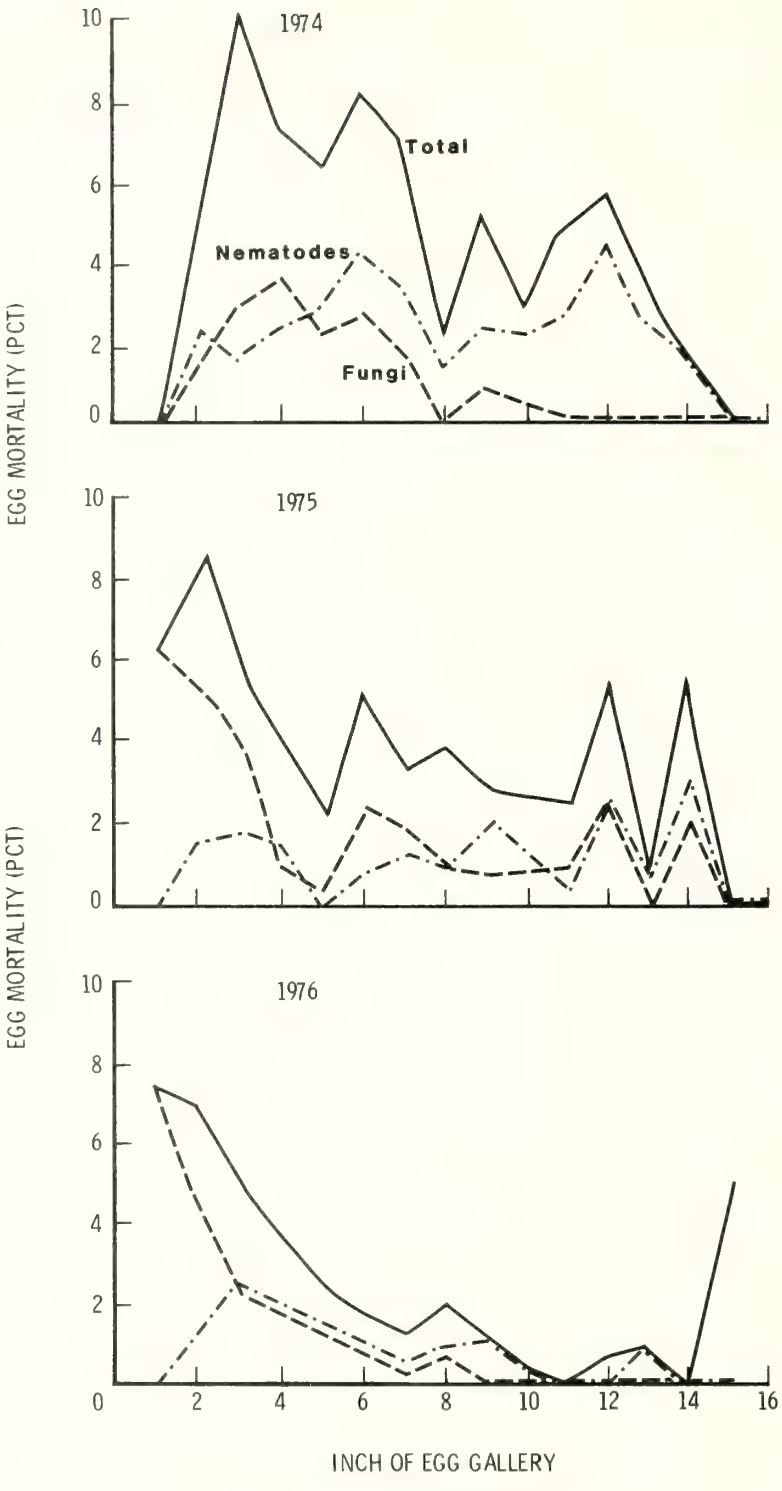

Figure 28.—Total mountain pine beetle egg mortality and mortality due to nematodes and fungi during laboratory studies in 3 years: 1974, 1975, 1976.

windfalls with parasitism of 30 percent or more, and standing trees with parasites in the base. When 21 or more parasites and predators per ft^2 (930 cm^2) of bark surface were present, mountain pine beetle populations were reduced (Bedard[5]).

Woodpeckers consume large numbers of beetles and cause the death of many more from desiccation when the birds open the bark. Prey size is an important factor affecting predation by woodpeckers (Koplin and Baldwin 1970). Trees containing small larvae tend to be avoided and woodpeckers concentrate on trees containing large larvae. At high elevations in northwest Wyoming, woodpeckers preyed mostly on parent beetles because of the small size of larvae (Amman 1973). During epidemics, woodpeckers are believed to have an insignificant effect on mountain pine beetle production (Berryman 1976). However, during endemic periods, they may play an important role in keeping a beetle population in check.

Several factors limit the effectiveness of insect parasites and predators. For *Coeloides* (DeLeon 1935a), these factors include:

1. It is found generally in *Ips*-infested material and is insufficient in number during the first few years of a mountain pine beetle infestation to destroy many of the larvae.
2. The main generation of *Coeloides* stays in the tree almost a year after the host beetle has been killed. Then, instead of catching up with the outlying groups of mountain pine beetles, the parasites stay within the original epicenter.
3. It increases in numbers slowly.
4. *Coeloides* is parasitized by *Eurytoma* sp. (Eurytomidae) and *Gelis* sp. (Ichneumonidae).
5. Thick bark limits parasitism by *Coeloides*.[5]

The thick bark of sugar pine excludes most parasites and predators except predacious beetles (Struble 1942). The bark of ponderosa pine is even more limiting to parasites and predators than the bark of sugar pine (Dahlsten and Stephen 1974).

The effect of predators on flying beetles is difficult to measure. The robber fly, *Laphria gilva* (L.), killed about 1 percent of flying mountain pine beetles in ponderosa pine stands of the Black Hills (Schmid 1969). Large numbers of robber flies were captured in passive traps in lodgepole pine stands (R. F. Schmitz, personal communication, January 1981).

The impact of birds on mountain pine beetle populations during the flight period can be substantial. Stomach content analysis of 18 birds revealed 15 with mountain pine beetle adults ranging in numbers between 1 and 289, and up to 20 percent of the food volume (Rust[6]). Nighthawks contained the most beetles, averaging 76 ($n = 10$), while the three-toed and hairy woodpeckers averaged only 2 beetles ($n = 5$). However, the following year, quantities of beetles taken by these birds was reversed—nighthawks averaged 5 beetles ($n = 14$), and woodpeckers averaged 33 ($n = 8$). Rust[6] pointed out that the heavy concentration of mountain pine beetles had shifted to another area the second year. Because the nighthawks stayed within their established breeding grounds, they had fewer beetles to prey upon the second year. Woodpeckers, on the other hand, moved to the area with the greater beetle population.

Stallcup[7] estimated from bird censuses and stomach analyses that birds consumed 8.5 percent of adult beetles during the beetles' flight period in a ponderosa pine stand of Colorado. A number of birds not previously reported as predators of the beetle were observed (table 7).

These observations suggest that birds could have a substantial impact on flying mountain pine beetle populations.

Intraspecific competition.—Competition has long been regarded as one of the principal density-dependent mortality factors of insect populations. Laboratory populations of mountain pine beetles under attack densities of 3, 9, and 18/ft^2 (930 cm^2) of bark surface in lodgepole pine billets produced 3.8, 2.2, and 0.6 adults/attack, respectively (Cole 1962). Under similar conditions, beetle production increased to the apparent capacity of the space and food, and then did not change throughout the higher gallery densities (Amman and Pace 1976) (fig. 29). In a laboratory study using artificial media for larval food, initially dense larval populations stimulated larval feeding; but as larvae matured they killed siblings without consuming them (entomocide) (W. Cole 1973). Entomocide and cannibalism reduce larval density and bring the population into equilibrium with food quantity and space (phloem volume). Another effect of competition (crowding) during larval development is reduced oviposition by the resulting new adults (W. Cole 1973), with egg production varying inversely with crowding density.

Low attack densities (Berryman 1976; Klein and others 1978) or low gallery densities (Amman and Pace 1976) result in high brood per parent ratios (fig. 30). But both attack and gallery densities must be high enough to assure that resinosis does not kill the brood.

[5]Bedard, W. D. The relation of parasites to mountain pine beetle control in western white pine. Washington, DC: U.S. Department of Agriculture, Bureau of Entomology; 1933. 7 p. Unpublished report.

Bedard, W. D. Preliminary report relative to biological factors in the control of the mountain pine beetle 1937 investigations. Washington, DC: U.S. Department of Agriculture, Bureau of Entomology; 1938. 23 p. Unpublished report.

Bedard, W. D. Biological factors in the control of the mountain pine beetle. Washington, DC: U.S. Department of Agriculture, Bureau of Entomology; 1939. 19 p. Unpublished report.

[6]Rust, Henry J. Relation of insectivorous birds to the mortality of the mountain pine beetle during the flight period. Couer d'Alene, ID: U.S. Department of Agriculture, Bureau of Entomology, Forest Insect Field Station; 1929. 5 p. Unpublished report.

Rust, Henry J. Relation of insectivorous birds to the mortality of the mountain pine beetle during the flight period. Couer d'Alene, ID: U.S. Department of Agriculture, Bureau of Entomology, Forest Insect Field Station; 1930. 11 p. Unpublished report.

[7]Stallcup, Patrick L. A method for investigating avian predation on the adult Black Hills beetle. Fort Collins, CO: Colorado State University; 1963. 60 p. Thesis.

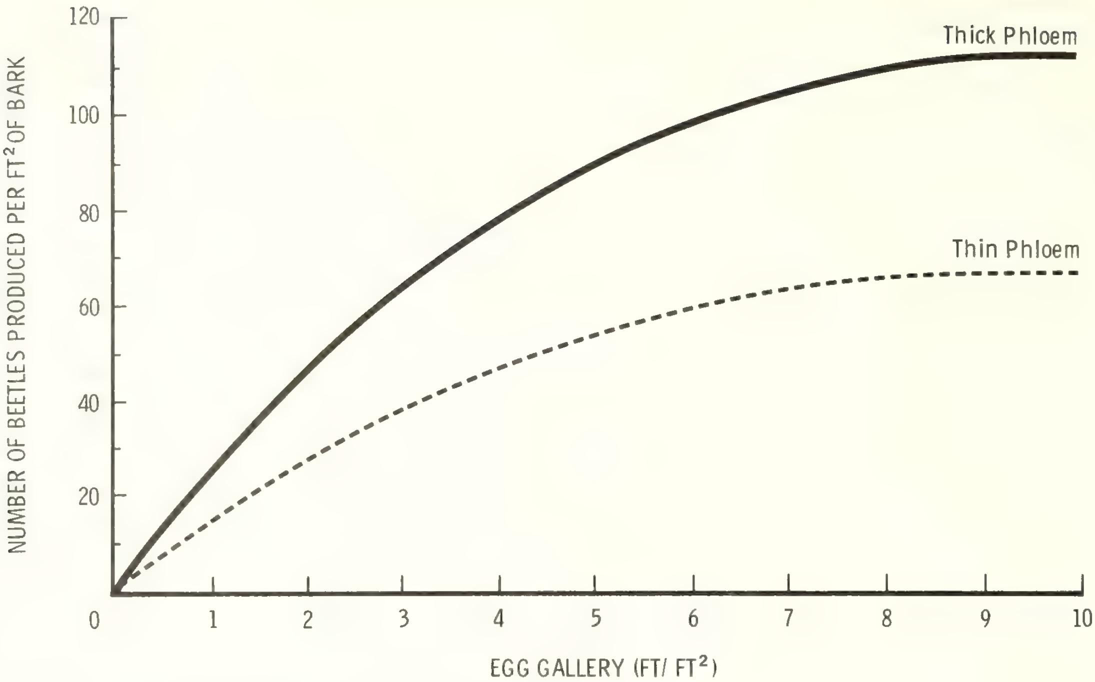

Figure 29.—Mountain pine beetle production per unit area of bark in relation to egg gallery density for two phloem thickness categories (Amman and Pace 1976). (See regression statistics in appendix.)

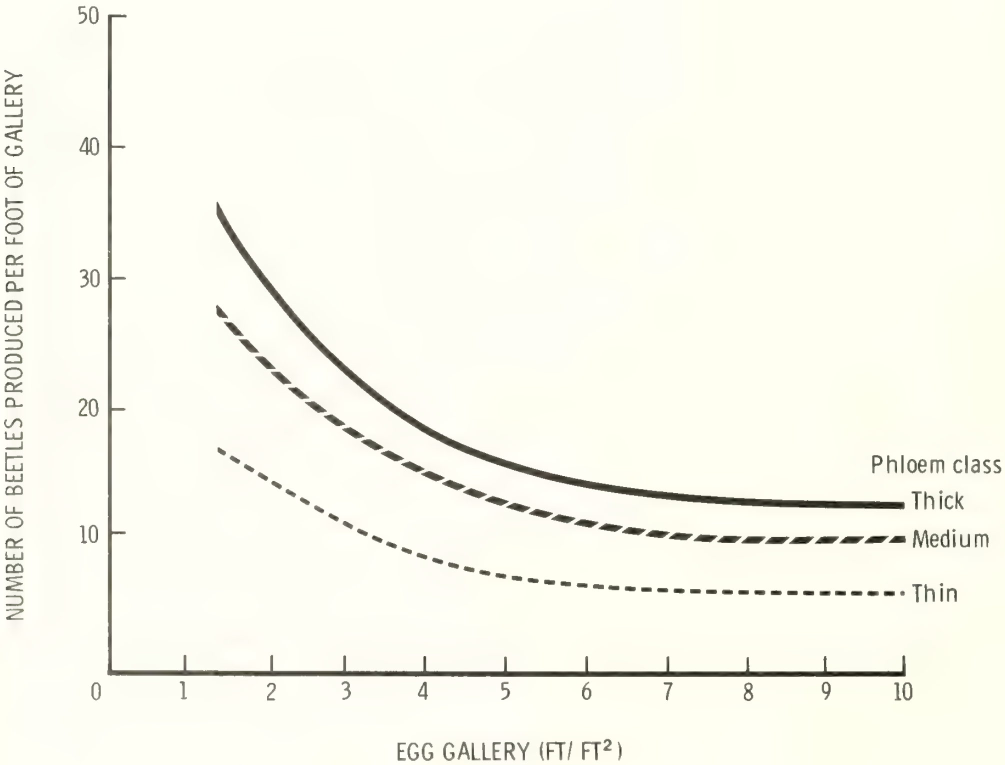

Figure 30.—Mountain pine beetle production per unit length of egg gallery for three phloem thickness categories. (See regression statistics in appendix.)

Interspecific competition.—Interspecific competition has little impact on epidemic mountain pine beetle populations in lodgepole pine (Berryman 1976). Competitors generally use smaller trees and portions of large trees unoccupied by mountain pine beetles. However, in ponderosa pine, wood borer larvae (Cerambycidae) impact mountain pine beetle populations by destroying mountain pine beetle larvae while both are feeding in the phloem (McCambridge and others 1979; Blackman 1931).

Resin.—The resinous response of lodgepole pine to mountain pine beetle infestation occurs when the beetle chews through resin ducts (Shrimpton 1978). The rate and density of attacks greatly influence the amount of resin available for flushing out ("pitching out" is the common term) beetles and hence success of attacks. A few attacks, or many attacks that occur over many days, usually are pitched out or beetles abandon the tree (Amman 1975a, 1980). Even when egg gallery is constructed and eggs are laid at low attack or gallery densities, the galleries are inundated by resin, thus killing eggs and larvae (Reid and Gates 1970). Low larval survival has been reported for bark with dense cortical resin canals (Berryman 1976). However, overall, studies over many years show losses to resin are minimal (Cole 1975, 1981).

Drying.—Host drying following infestation by mountain pine beetles is an important factor in mortality of beetle brood (Blackman 1931; Cole 1975), and probably is one of the deciding factors causing beetle populations to return endemic before killing most of the small diameter trees in a stand (Cole and others 1976). Excessive drying of the phloem deprives developing brood of necessary moisture. Larvae cease feeding and shrivel as they desiccate. Drying is usually more severe in small diameter lodgepole pine (Amman 1977) (fig. 31), and is believed partially related to sapwood depth (Amman 1978). Sapwood contains more moisture then heartwood (Reid 1961) and is usually thinner in small trees than in large ones (fig. 32). Harvey (1979) found that 6-inch (15-cm) d.b.h. lodgepole pines contained proportionately only one-half the sapwood of trees 8 inches (20 cm) d.b.h. and larger. Rate of lodgepole pine drying also is affected by blue-stain fungi (Reid 1961). Trees drying most rapidly following beetle infestation contained more moisture at time of brood emergence (Amman 1977). These trees had profuse growth of blue-stain fungi throughout the sapwood as shown in figure 33a. (Figure 33 is on the inside back cover). Trees with sporadic and sparse growth of fungi in the sapwood dried excessively (fig. 33b). In addition to tree and blue-stain fungi, drying is also influenced by beetle attack behavior. As attack and gallery densities increase, drying also increases, probably because of greater opening of the bark (Cole and others 1976).

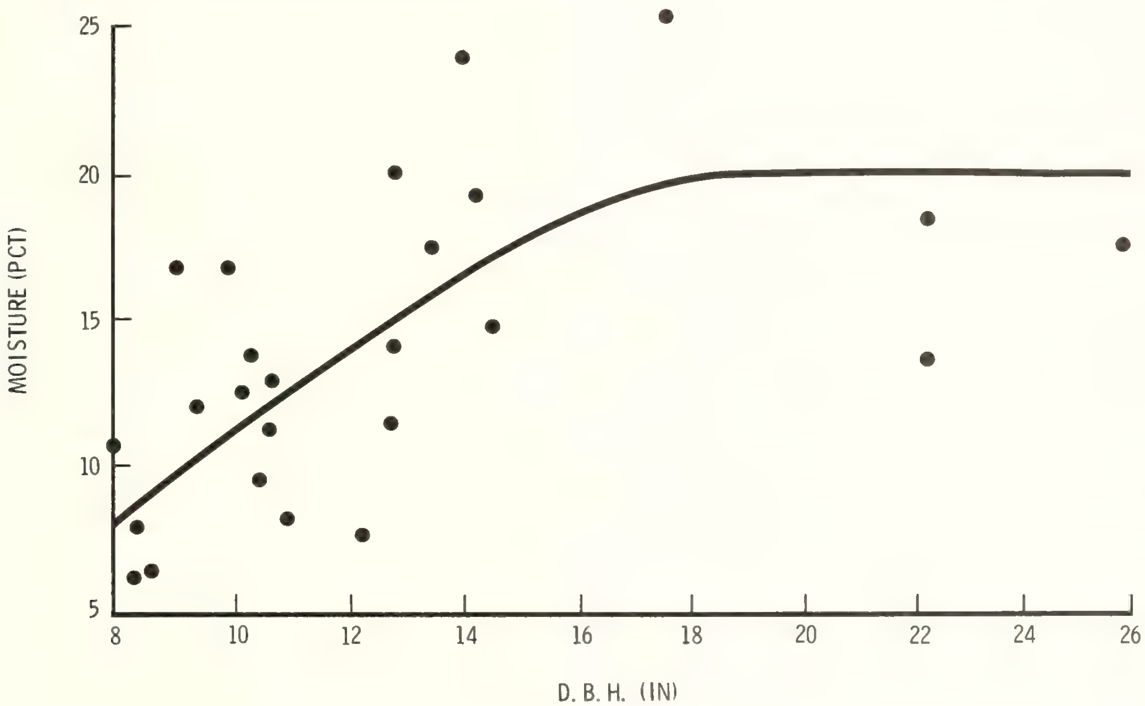

Figure 31.—Moisture content of the sapwood of infested trees 3 weeks prior to emergence of mountain pine beetle brood adults, Wasatch-Cache National Forest, Utah (Amman 1976).

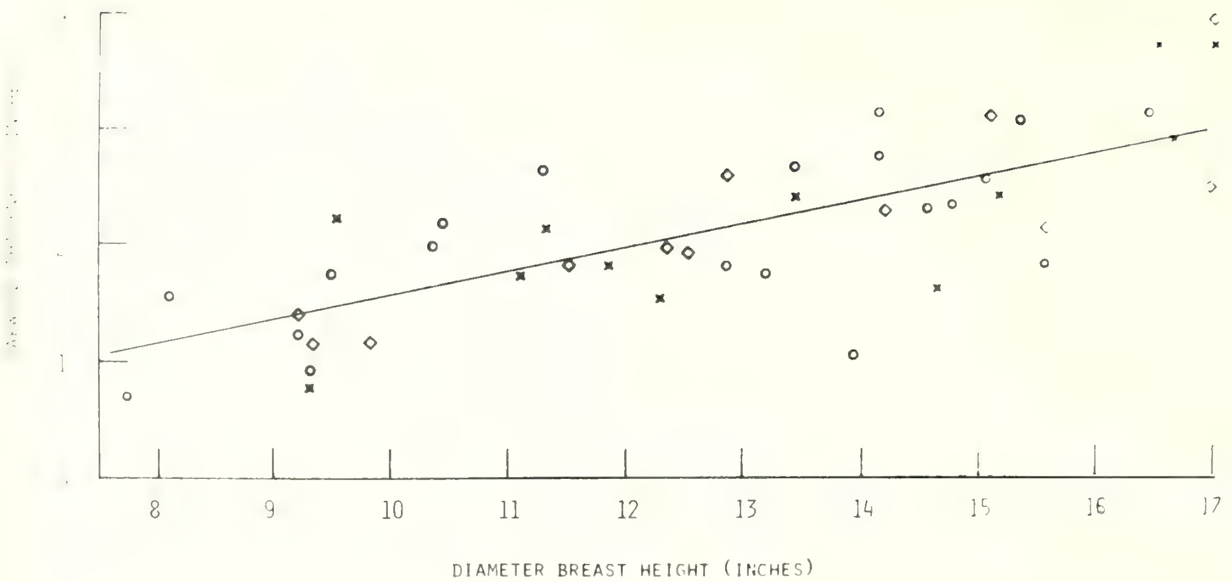

Figure 32.—Sapwood thickness of infested lodgepole pine in relation to diameter at breast height for 3 years, 1971–73, Wasatch-Cache National Forest, Utah (Amman 1978). (See regression statistics in appendix.)

Temperature.—Cold winter temperatures also kill many beetles (Cole 1975). Losses to freezing temperatures are influenced by an interaction of temperature and time. Because there is a lag of subcortical temperature behind air temperatures, very cold temperatures for a brief period do not kill as many beetles as somewhat warmer temperatures that persist for a longer time (Beal 1934). For example, temperatures dipped to −44° F (−40° C) at Moran, Wyo., briefly in January 1963 (U.S. Weather Bureau 1963). Much of the population was killed, but pockets of infested trees and thick-barked portions of others escaped freezing. Mountain pine beetles can increase or decrease their cold hardiness at any time of the year, depending upon existing temperatures (Yuill 1941). Cold hardiness varies by host species; beetles from lodgepole and ponderosa pines are more cold hardy than those from sugar pine in California (Yuill 1941).

Even temperatures occurring during an average winter may interact with the stage of overwintering brood to cause extensive mortality (fig. 34). Eggs and small larvae are more susceptible to winterkill than large larvae (Amman 1973; Reid 1962a), even though the first three larval stages contain proportionately the same amount of glycerol, an alcohol that protects against freezing (Sômme 1964). As the beetle disposes of water, thereby increasing the proportion of glycerol, it can tolerate colder temperatures without freezing. All eggs and pupae die during the winter. Young brood resulting from late August and September attacks, young brood occurring toward the end of long galleries, and young brood of occasional second attacks by parents will usually be affected more adversely than the older brood occurring from early attacks and short galleries. Large beetle larvae are most susceptible to cold temperatures in the early spring after feeding is resumed. Sudden freezing temperatures can cause much larval mortality at this time.

High temperatures in lodgepole forests of most of the Rocky Mountains are not likely to cause beetle mortality. Solar heat was tested as a means of destroying brood under the bark of lodgepole pine (Patterson 1930). Beetle brood safely endured temperatures of 100° F (37° C). However, temperatures between 110° and 120° F (43° and 49° C) killed the brood, requiring only 20 to 30 minutes of exposure to 120° F.

Distribution of mortality.—Most beetle mortality factors are unevenly distributed among trees and bark samples, although the effect of abiotic factors, as expected, tends to be more evenly distributed among trees and samples (table 9). These differences in distribution of mortality factors among and within trees and by stage of infestation (endemic, epidemic, and postepidemic) can greatly influence their overall effect on mountain pine beetle populations.

Within trees, parasites are more commonly found in the upper portions, and predators in the lower portions of western white pine trees in northern Idaho (Bedard[5]), in lodgepole pine trees in northwestern Wyoming (Bean[8]), and in sugar pine trees in California (Dahlsten and Stephen 1974). Almost all *Coeloides* were in the middle third of the tree, while the predator *Medetera* was primarily in the basal third in lodgepole pine. Trees infested early in the flight period tend to contain more *Medetera* than those infested later (Schmid 1970b).

Losses of beetles to different mortality agents also varied according to stage of infestation in 1973–74: endemic (Hyalite Canyon, Gallatin National Forest, Mont.; Upper Salmon River, Sawtooth National Forest, Idaho); epidemic (Logan Canyon, Wasatch-Cache National Forest, Utah; Warm River, Targhee National Forest, Idaho); and postepidemic (Elkhart Park, Bridger-Teton National Forest, Wyo.; Turpin Meadows, Bridger-Teton National Forest, Wyo.).

[8]Bean, James L. The effects of control measures on the mountain pine beetle (*Dendroctonus monticolae* Hopkins) in lodgepole pine, Teton National Forest, Jackson, Wyoming. About 1949. Unpublished report. 22 p., plus figures and tables.

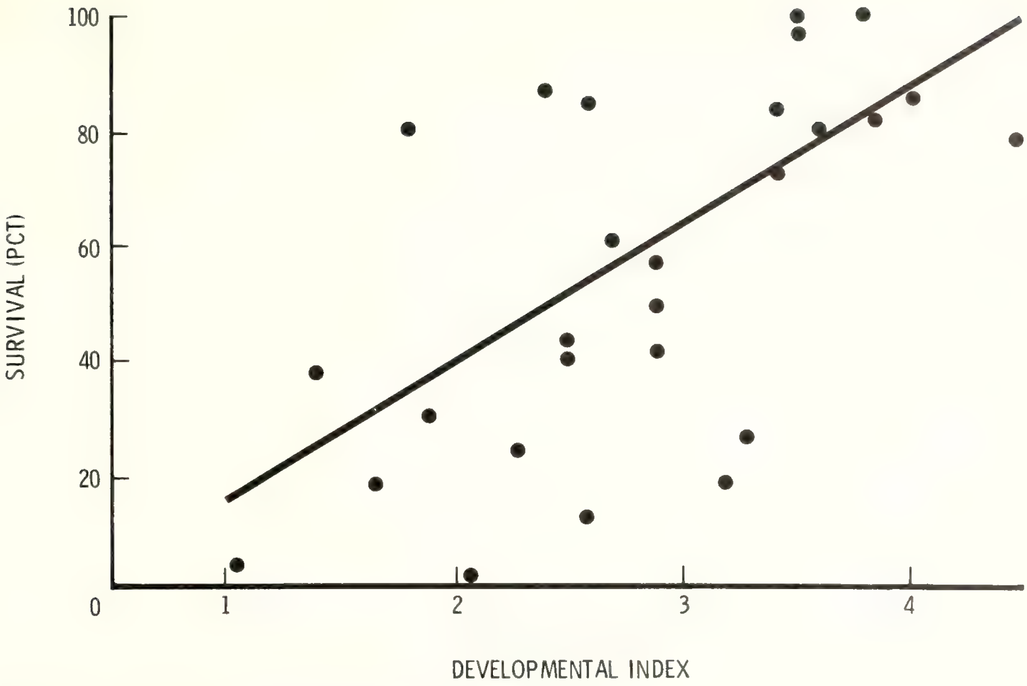

Figure 34.—Survival of mountain pine beetle brood during the winter is related to how advanced larval development is in the fall. Developmental Index: 1 = egg; 2 = first instar; 3 = second instar; 4 = third instar.

Table 9.—Percent of trees (Tr.) and samples (Sa.) in which losses of mountain pine beetle to specific mortality factors[1] were observed, Wasatch-Cache National Forest, Utah

Year	Number		WC		BC		PA		T		PI		CL		MD		WP		UNK	
	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.
									Percent											
									Fall sample											
									Trees ≤8.9 in (22.6 cm) d.b.h.											
1974-75	2	4							50.0	25.0									50.0	25.0
1975-76	5	10							100.0	70.0					20.0	10.0				
1977-78	1	2							100.0	50.0	100.0	50.0								
1978-79	1	2							100.0	50.0										
									Trees 9.0-11.9 in (22.9-30.2 cm) d.b.h.											
1970-71	1	22			9.1	4.5			18.2	9.1			9.1	4.5	36.4	18.2			9.1	4.5
1971-72	8	16	50.0	31.2	62.5	50.0	25.0	12.5	37.5	18.8	25.0	12.5			62.5	43.8			87.5	68.8
1972-73	4	8	25.0	25.0	25.0	25.0			50.0	37.5	25.0	12.5			25.0	12.5			25.0	12.5
1973-74	11	22	81.8	68.2	18.2	18.2	9.1	9.1			9.1	4.5	9.1	4.5	72.7	54.5	18.2	13.6	9.1	4.5
1974-75	8	16	37.5	18.8	75.0	56.2			50.0	43.8					25.0	18.8			37.5	37.5
1975-76	8	16							62.5	37.5										
1976-77	4	8			25.0	12.5	25.0	12.5	75.0	37.5					25.0	25.0				
1977-78	4	8	25.0	25.0	25.0	25.0	50.0	25.0	50.0	37.5			25.0	12.5	100.0	75.0				
1978-79	6	12	33.3	25.0	33.3	25.0	16.7	8.3	33.3	16.7					16.7	16.7				
									Trees 12.0-14.9 in (30.5-37.9 cm) d.b.h.											
1970-71	1	2																100.0	50.0	
1971-72	3	6	33.3	16.7	66.7	33.3			33.3	16.7					66.7	33.3			100.0	83.3
1972-73	6	12	66.7	41.7	50.0	33.3			50.0	33.3	50.0	33.3			50.0	33.3			66.7	33.3
1973-74	6	12	83.3	75.0			16.7	16.7							83.3	66.7		16.7	16.7	16.7
1974-75	8	16	50.0	25.0	50.0	31.2	12.5	6.2	37.5	31.2					37.5	31.2			25.0	25.0
1975-76	5	10							80.0	70.0					20.0	10.0				
1976-77	7	14			14.3	7.1	14.3	7.1	14.3	7.1					57.1	35.7				
1977-78	3	6	33.3	33.3	66.7	33.3	33.3	16.7	66.7	50.0	33.3	16.7			100.0	50.0				
1978-79	4	8	25.0	12.5	50.0	25.0			75.0	50.0	25.0	12.5			100.0	62.5				
									Trees 15.0+ in (38.1 cm) d.b.h.											
1971-72	1	2	100.0	100.0	100.0	100.0													100.0	50.0
1972-73	2	4	100.0	50.0	100.0	50.0			50.0	25.0					50.0	50.0			50.0	25.0
1973-74	3	6	66.7	50.0	33.3	33.3									66.7	50.0				
1974-75	2	4			50.0	25.0			50.0	50.0	50.0	25.0			50.0	50.0				
1975-76	2	4							50.0	25.0										
1976-77	7	14					14.3	14.3	42.8	21.					57.1	50.0				
1977-78	6	12	33.3	25.0	50.0	41.7	16.7	16.7	33.3	16.7					100.0	83.3				
1978-79	1	2	100.0	100.0	100.0	50.0									100.0	100.0				
									Spring sample											
									Trees ≤8.9 in (22.6 cm) d.b.h.											
1974-75	2	4							100.0	100.0			50.0	25.0						
1975-76	5	10							100.0	90.0	40.0	20.0	20.0	10.0						
1977-78	1	2																		
1978-79	1	2							100.0	100.0										
1979-80	1	2							100.0	50.0										
									Trees 9.0-11.9 in (22.9-30.2 cm) d.b.h.											
1970-71	11	22			18.2	13.6			81.8	77.3	18.2	13.6	18.2	9.1	9.1	4.5				
1971-72	8	16			50.0	31.2			100.0	93.8			62.5	43.8			25.0	12.5		
1972-73	4	8					25.0	12.5	100.0	75.0	25.0	12.5					25.0	12.5		
1973-74	11	22			9.1	4.5			90.9	81.8	72.7	50.0	18.2	9.1			63.6	54.5	27.3	18.2
1974-75	8	16	25.0	12.5	12.5	6.2			87.5	81.2	25.0	18.8			12.5	6.2	50.0	37.5		
1975-76	8	16							100.0	93.8	25.0	25.0	37.5	18.8						
1976-77	4	8							75.0	62.5	50.0	37.5	50.0	37.5					25.0	12.5
1977-78	4	8			25.0	25.0			100.0	75.0	75.0	50.0	50.0	25.0			75.0	62.5		
1978-79	6	12	16.7	8.3					100.0	91.7	33.3	25.0					50.0	33.3		
1979-80	5	10	20.0	10.0			20.0	10.0	100.0	80.0			20.0	10.0			20.0	20.0		
									Trees 12.0-14.9 in (30.5-37.9 cm) d.b.h.											
1970-71	1	1	100.0	50.0					100.0	100.0			100.0	50.0						
1971-72	3	6	33.3	33.3	66.7	50.0			100.0	100.0			33.3	16.7						
1972-73	6	12	16.7	8.3			16.7	16.7	83.3	83.3	16.7	16.7	50.0	41.6						

(con.)

Table 9.—(con.)

Year	Number		WC		BC		PA		T		D		MD		CD		WP		UNK	
	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.	Tr.	Sa.
									Percent											
1973-74	6	12							66.7	50.0	16.7	16.7	50.0	50.0			16.7	16.7	16.7	16.7
1974-75	8	16	25.0	25.0	37.5	37.5	12.5	6.2	100.0	93.8	25.0	12.5	37.5	25.0	25.0	12.5	50.0	43.8		
1975-76	5	10	20.0	10.0	20.0	20.0	20.0	10.0	100.0	100.0	20.0	10.0	60.0	40.0						
1976-77	7	14							100.0	71.4	42.8	28.6	85.7	50.0					14.3	14.3
1977-78	3	6	33.3	16.7	66.7	33.3			66.7	66.7	66.7	33.3	100.0	66.7			66.7	33.3		
1978-79	4	8	50.0	37.5	50.0	25.0			100.0	100.0			25.0	25.0					25.0	12.5
1979-80	4	8			25.0	12.5			100.0	87.5	50.0	25.0					50.0	37.5		
									Trees 15.0 + in (38.1 cm) d.b.h.											
1971-72	1	2			100.0	50.0			100.0	100.0										
1972-73	2	4							100.0	75.0			50.0	25.0						
1973-74	3	6							100.0	83.3			33.3	33.3			33.3	33.3		
1974-75	2	4							100.0	100.0	50.0	50.0	100.0	75.0			50.0	50.0		
1975-76	2	4	50.0	25.0					100.0	75.0										
1976-77	7	14							71.4	64.3	42.8	35.7	42.8	28.6						
1977-78	6	12			33.3	16.7	16.7	8.3	100.0	91.7	33.3	25.0	100.0	83.3			16.7	16.7		
1978-79	1	2							100.0	100.0	100.0	50.0	100.0	50.0						
									Early summer sample											
									Trees ≤ 8.9 in (22.6 cm) d.b.h.											
1974-75	2	4	50.0	25.0			50.0	50.0												
1975-76	5	10									40.0	20.0	40.0	40.0	20.0	10.0				
1977-78	1	2											100.0	50.0						
1978-79	1	2					100.0	50.0									100.0	50.0		
1979-80	2	4					50.0	50.0			50.0	25.0								
									Trees 9.0-11.9 in (22.9-30.2 cm) d.b.h.											
1970-71	11	22	36.4	27.3	45.5	40.9	18.2	13.6	9.1	9.1	18.2	13.6	54.5	31.8			9.1	4.5		
1971-72	8	16					12.5	6.2			50.0	31.2			25.0	18.8	50.0	37.5		
1972-73	4	8			50.0	25.0	75.0	62.5												
1973-74	11	22					72.7	50.0	9.1	4.5	9.1	4.5	27.3	13.6						
1974-75	8	16	12.5	6.2			62.5	56.2	12.5	6.2	25.0	12.5			25.0	25.0				
1975-76	8	16					25.0	12.5	25.0	12.5	25.0	12.5	25.0	25.0						
1976-77	4	8	25.0	12.5			100.0	100.0							25.0	25.0				
1977-78	4	8					25.0	12.5	25.0	12.5	25.0	12.5	75.0	62.5	50.0	50.0				
1978-79	6	12	16.7	8.3			50.0	41.7			16.7	8.3			16.7	8.3	16.7	8.3		
1979-80	4	8			25.0	12.5									50.0	37.5				
									Trees 12.0-14.9 in (30.5-37.9 cm) d.b.h.											
1970-71	1	2	100.0	100.0	100.0	100.0					100.0	100.0								
1971-72	3	6	33.3	16.7			33.3	16.7			33.3	33.3					33.3	16.7		
1972-73	6	12			66.7	50.0	50.0	33.3			33.3	25.0								
1973-74	6	12					16.7	8.3	50.0	41.6	50.0	33.3								
1974-75	8	16			12.5	6.2	75.0	56.2			25.0	18.8	25.0	12.5	37.5	31.2				
1975-76	5	10	20.0	10.0			60.0	50.0			40.0	20.0	60.0	40.0						
1976-77	7	14					85.7	78.6					28.6	21.4						
1977-78	3	6	33.3	16.7					33.3	16.7	33.3	16.7	66.7	33.3	33.3	16.7				
1978-79	4	8					75.0	62.5			25.0	12.5			25.0	12.5	25.0	12.5		
1979-80	4	8			25.0	12.5	50.0	37.5							50.0	50.0				
									Trees 15.0 + in (38.1 cm) d.b.h.											
1971-72	1	2					100.0	100.0												
1972-73	2	4			50.0	50.0					50.0	25.0								
1973-74	3	6					33.3	33.3	66.7	50.0	66.7	50.0	33.3	16.7						
1974-75	2	4			50.0	25.0	100.0	100.0			50.0	25.0								
1975-76	2	4											50.0	25.0						
1976-77	7	14			14.3	7.1	85.7	71.4			42.8	21.4	42.8	21.4			14.3	14.3		
1977-78	6	12	33.3	33.3							33.3	16.7	33.3	25.0	16.7	8.3				
1978-79	1	2																		

[1]Abbreviations of mortality factors are:
WC = competition within brood of an individual egg gallery
BC = competition among brood of several egg galleries
CL = clerid
CD = *Coeloides*
MD = *Medetera*
PA = pathogen
WP = woodpecker
T = temperature
D = drying
PI = pitch
UNK = unknown

Table 10.—Mountain pine beetle survival and mortality to specific causes in three classes of infestation (endemic, epidemic, and postepidemic) and three heights in lodgepole pine

Item		Height above ground and infestation class											
		4.5 ft (1.4 m)			12 ft (3.7 m)			20 ft (6.1 m)			Heights combined		
		End.	Epi.	Post.	End.	Epi.	Post.	End.	Epi.	Post.	End.	Epi.	Post.
Samples (232 cm^2)	No.	16	20	24	16	20	24	8	14	8	40	54	56
Starting populations	No.	1,621	1,693	2,571	1,048	1,467	1,891	501	1,124	668	3,170	4,284	5,130
Emerging	No.	56	29	15	47	16	8	14	15	5	117	60	28
adults	%	3.5	1.7	.6	4.5	1.1	.4	2.8	1.3	.7	3.7	1.4	.5
Mortality factors:													
Within[1]	No.	48	72	1	64	17	10	0	112	0	112	201	11
competition	%	3.0	4.3	.05	6.1	1.2	.5	0	10.0	0	3.5	4.7	.2
Between[2]	No.	13	110	15	28	0	27	0	128	16	41	238	58
competition	%	.8	6.5	.6	2.7	0	1.4	0	11.4	2.4	1.3	5.6	1.1
Clerid	No.	19	6	4	9	4	4	1	7	0	29	17	8
	%	1.2	.4	.2	.9	.3	.2	.2	.6	0	.9	.4	.2
Coeloides	No.	17	26	1	5	17	0	0	31	0	22	74	1
	%	1.0	1.5	.05	.5	1.2	0	0	2.8	0	.7	1.7	.02
Medetera	No.	58	246	2	49	219	2	20	94	0	127	559	4
	%	3.6	14.5	.1	4.7	14.9	.1	4.0	8.4	0	4.0	13.0	.08
Pathogen	No.	0	35	5	15	88	0	0	0	0	15	123	5
	%	0	2.1	.2	1.4	6.0	0	0	0	0	.5	2.9	.1
Woodpecker	No.	35	142	33	25	354	88	0	153	75	60	649	196
	%	2.2	8.4	1.3	2.4	24.1	4.7	0	13.6	11.2	1.9	15.2	3.8
Temperature	No.	454	574	803	189	291	599	81	212	131	724	1,077	1,533
	%	28.0	33.9	31.2	18.0	19.8	31.7	16.2	18.9	19.6	22.8	25.1	29.9
Drying	No.	306	158	564	308	275	167	84	144	106	698	577	837
	%	18.9	9.3	21.9	29.4	18.7	8.8	16.8	12.8	15.9	22.0	13.5	16.3
Pitch	No.	0	12	11	0	35	24	0	2	3	0	49	38
	%	0	.7	.4	0	2.4	1.3	0	.2	.4	0	1.1	.7
Unknown	No.	615	283	1,117	309	151	962	301	226	332	1,225	660	2,411
	%	37.8	16.7	43.4	29.4	10.3	50.9	60.0	20.1	49.8	38.7	15.4	47.1

[1]Competition within brood of an individual egg gallery.

[2]Competition among brood of several egg galleries.

Predation by clerids, although usually light, was greater at 4.5 ft (1.4 m) above ground than higher in the trees in endemic populations, slightly higher at the 20-ft (6.1-m) level in epidemic populations, and about equal in 4.5- and 12-ft (1.4- and 3.7-m) levels during the postepidemic period (table 10). Overall, predation by clerids was greater in endemic infestations.

Coeloides parasitized more beetles at all three sample heights in epidemic infestation than in the other two infestation types. However, this accounted for a maximum of only 2.8 percent of the beetle population at any one height. The amount of parasitism was particularly low (0.02 percent) in the postepidemic infestations. This is probably partly related to the excessive drying of infested trees that occurs during the postepidemic period (Cole and others 1976), which may affect *Coeloides* as much or more than its mountain pine beetle host. Also, *Coeloides* may have switched to *Ips* species, which are commonly parasitized by *Coeloides* (DeLeon 1935a) and which are more abundant than mountain pine beetles in the postepidemic period (Evenden and Gibson 1940).

Medetera, the most important insect predator, caused greatest mortality in epidemic infestations, accounting for 13 percent of the beetles. Predation was about equal in the 4.5- and 12-ft (1.4- and 3.7-m) samples, but less in the 20-ft (6.1-m) sample. Schmid (1971) reported similar findings, with greatest numbers 5 to 10 ft (1.5 to 3.0 m) above ground in ponderosa pine. Predation was extremely light in the postepidemic infestations, and probably is related to excessive drying of host trees that either affected *Medetera* directly or indirectly by reducing the number of prey. *Medetera* larvae desiccate easily (Schmid 1971). Also, possible association of *Medetera* with the more numerous *Ips* would reduce *Medetera*'s effect on mountain pine beetles.

Woodpeckers accounted for greater predation in epidemic infestations than in endemic and postepidemic infestations. The low amount of woodpecker predation in endemic infestations may be due to sparse woodpecker populations during such periods. Most woodpecker predation occurred in the 12-ft (3.7-m) samples, with the least at 4.5-ft (1.4-m) samples. The smaller amount of predation at 4.5 ft (1.4 m) is probably related to thicker bark found at that height, compared to higher on the tree or to deep snow that prevented access. Dahlsten and Stephen (1974) observed that predation of mountain pine beetles by woodpeckers in sugar pine was greater in the upper half of the tree, which probably also was related to thinner bark in that portion. Woodpeckers tend to feed on beetles that are easiest to reach and are an acceptable size. Woodpeckers tend to avoid small larvae when larger prey are available (Koplin and Baldwin 1970; Amman 1973).

Beetle mortality attributable to pathogens—probably the fungus *Beauveria bassiana* (Balsamo) Vuillemin, a pathogen be-

ing investigated by Whitney and others (1978)—was low but occurred most commonly in epidemic infestations. The very low incidence of disease during postepidemic infestations may have been because of excessive drying of the trees during this phase of the infestation.

Evaluation of Mortality Factors

It is difficult to evaluate the relative importance of mortality factors that operate on any population for controlling or regulating influences. Previous work (Cole 1974, 1975) only evaluated mortality factors over a short time. Full evaluation requires simultaneous measuring of mortality attributable to all factors operating on several populations for a number of years, preferably throughout an infestation cycle. The following analysis covers such a period of sampling for mountain pine beetles in lodgepole pine.

Data Source.—Data were taken from infestations on three National Forests: Wasatch-Cache in northern Utah (Stillwater plot), Bridger-Teton in northwestern Wyoming, and Targhee in southeastern Idaho. Another infestation on the Wasatch-Cache National Forest (Logan Canyon plot) was followed as a special case because the population has remained at a "high endemic" level over 9 years and shows particularly interesting relationships between mortality factors and population fluctuations.

Mountain pine beetle populations were sampled between 1964 and 1977 by tree diameter and infestation stage (preepidemic, epidemic, and postepidemic). The infested tree was the sampling unit. To minimize between-tree variance, trees were stratified by diameter classes: 9-inch (23-cm) including trees 11.9 inches (30 cm) d.b.h. and less; 12-inch (30.5-cm) including trees 12 through 14.9 inches (30.5 to 37.8 cm) d.b.h.; and 15-inch (38-cm) d.b.h. and greater. The random sampling technique (Carlson and Cole 1965) focused on critical within-tree measurements and sampling efforts.

Two 6-inch by 6-inch (232-cm^2) samples were taken per tree each sample date. The samples were selected at random within an area $\pm$ 1 ft (30.5 cm) of breast height. Insects within the samples were recorded as individuals living and dead (by cause of death) within each developmental stage of the beetle. Previous work (Cole 1975) demonstrated that observations at five developmental intervals within a generation were sufficient to detect population mortality by cause of death among developmental stages. Pertinent developmental intervals within the life cycle for observations of mortality are as follows:

0. Base population—	The total of live and dead eggs and larvae from the late fall sample.
1. Late fall—	Number of live larvae entering winter.
2. Early spring—	Number of larvae that survived the winter.
3. Summer—	Number of mature larvae and pupae.
4. Late summer—	Number of emerging new adults, obtained by caging the sample area.

We used the abridged cohort life table, in which a generation of beetles is sampled at particular points in time. However, the abridged cohort life table was not strictly followed because of destructive sampling and because emergence of new adults was equated with the end of life for that particular cohort (that is, death of the last individual). Consequently, flight mortality was not considered. In addition, individuals within the sample were assumed to be subjected to the same risks, and the survival of one individual was assumed to be independent of the survival of any other individual (Chiang 1968).

Ten individual mortality factors (risks) were measured:

1. Within competition (WC)—mortality from crowding of larvae within the same brood or egg gallery.
2. Between competition (BC)—mortality from crowding of larvae from two or more separate or different broods or egg galleries.
3. A predacious fly, *Medetera aldrichii* (MD).
4. Predacious beetles, *Thanasimus undatulus* and *Enoclerus sphegeus* (CL).
5. Insect parasites, primarily *Coeloides dendroctoni* (CD).
6. Woodpeckers (WP).
7. Temperature (T)—mortality from low winter temperatures.
8. Drying of the phloem (D), recorded as desiccation of the larvae.
9. Pitch (PI), recorded as inundation of larval galleries with pitch and drowning of larvae.
10. Unknown (UNK)—cause of death could not be determined.

Due to inadequacy of measurement techniques, not all mortality is readily definable or measurable and therefore is attributable to unknown causes.

Data Analysis.—The competing risks analysis (Chiang 1968) was used in most cases. Some terms are:

Risk of dying—	A mortality factor present in a population prior to the death of an individual within that population.
Cause of dying—	A mortality factor causing death of an individual in that population.
Crude probability—	The probability of death from a specific risk in the presence of all other risks evident in the uncontrolled insect population and as measured for construction of life tables.
General probability—	Probability of death (or survival) when the cause of death is not specified.

The approach used was to determine the probability of death, using competing risks analysis of life tables to evaluate mortality factors, singly and in combination (Cole 1981). The probability of death due to a mortality factor is the probability proportional to the total loss from all mortality factors. For example, if the probability of loss from all factors was 0.50, and from a single mortality factor was 0.10, then that single factor was contributing 0.10 of 0.50, or taking 0.05 of the total population.

Probability of survival.—As expected from previous population studies (Reid 1963; Cole and others 1976; Klein and others 1978), the largest populations occurred in large trees except in the preepidemic period when populations in 12- and 15-inch (30- and 38-cm) tree classes were similar (table 11; fig. 35). The probability of an individual surviving the entire egg-to-adult period increased with tree size during the preepidemic period (table 12; fig. 36). During the epidemic and postepidemic periods, probability of survival was greatest in the 12-inch (30-cm) diameter class and was approximately equal in the 9- and 15-inch (23- and 38-cm) classes.

Table 11.—Mountain pine beetle survival and mortality[1] by cause in three lodgepole pine diameter classes and three stages of infestation

Infestation	Observation	No. alive	No. dead	Numbers per sample										
				WC	BC	CL	CD	MD	PA	WP	T	D	PI	UNK
							Tree diameter class: 23 cm							
Pre-epidemic	0	69.64	0	0	0	0	0	0	0	0	0	0	0	0
	1	55.37	14.27	1.10	1.08	0	0	.25	0	0	.26	0	0	11.58
	2	30.36	25.01	1.23	1.25	0.03	0	.70	0	0.58	13.78	1.00	0	6.44
	3	8.21	22.15	.71	1.11	.01	0.35	.26	.39	.63	7.07	0.31	.11	11.20
	4	3.33	4.88	0	0	0	0	0	0	0	0	0	0	4.88
	Sum		*66.31*	*3.04*	*3.44*	*.04*	*.35*	*1.21*	*.39*	*1.21*	*21.11*	*1.31*	*.11*	*34.10*
Epidemic	0	93.60	0	0	0	0	0	0	0	0	0	0	0	0
	1	85.78	7.82	.75	.73	0	0	.48	0	.10	1.03	0	.20	4.53
	2	27.38	58.40	1.30	2.33	0	0	.38	.05	1.15	37.02	8.61	0	7.56
	3	19.35	8.03	.15	.35	.03	.30	.13	.18	.20	.17	.67	.03	5.82
	4	15.21	4.14	0	0	0	0	0	0	0	0	0	0	4.14
	Sum		*78.39*	*2.20*	*3.41*	*.03*	*.30*	*.99*	*.23*	*1.45*	*38.22*	*9.28*	*.23*	*22.05*
Post-epidemic	0	80.43	0	0	0	0	0	0	0	0	0	0	0	0
	1	69.96	10.47	1.97	2.95	.15	.03	1.84	.20	.03	2.12	.11	.32	.75
	2	26.84	43.12	.20	.86	.04	.01	.85	.14	1.65	12.39	4.80	.45	21.73
	3	13.24	13.60	0	0	.08	1.08	.06	.08	.62	.46	4.34	.02	6.86
	4	6.00	7.24	0	0	0	.02	0	.02	0	0	.07	0	7.13
	Sum		*74.43*	*2.17*	*3.81*	*.27*	*1.14*	*2.75*	*.44*	*2.30*	*14.97*	*9.32*	*.79*	*36.47*
							Tree diameter class: 30 cm							
Pre-epidemic	0	83.68	0	0	0	0	0	0	0	0	0	0	0	0
	1	70.78	12.90	.33	.58	0	.02	1.11	.84	0	.03	0	0	9.99
	2	32.70	38.08	.51	2.00	0	0	1.35	.27	2.33	15.33	.35	.14	15.80
	3	15.46	17.24	.55	.41	.03	.36	.86	1.01	1.58	6.15	.07	0	6.22
	4	7.42	8.04	0	0	0	0	0	0	0	0	0	0	8.04
	Sum		*76.26*	*1.39*	*2.99*	*.03*	*.38*	*3.32*	*2.12*	*3.91*	*21.51*	*.42*	*.14*	*40.05*
Epidemic	0	113.48	0	0	0	0	0	0	0	0	0	0	0	0
	1	103.65	9.83	1.63	2.10	0	0	1.65	0	.23	1.27	0	.15	2.80
	2	49.48	54.17	0	3.25	0	0	.43	.70	1.38	29.80	6.70	0	11.91
	3	30.04	19.44	0	0	.10	.48	.15	.05	.68	.10	.93	0	16.95
	4	15.14	14.90	0	0	0	0	0	0	0	0	0	0	14.90
	Sum		*98.34*	*1.63*	*5.35*	*.10*	*.48*	*2.23*	*.75*	*2.29*	*31.17*	*7.63*	*.15*	*46.56*
Post-epidemic	0	80.15	0	0	0	0	0	0	0	0	0	0	0	0
	1	66.99	13.16	2.50	1.54	.03	.08	2.10	.10	.18	3.10	0	0	3.53
	2	34.21	32.78	.40	.69	.03	.17	1.68	.28	.72	12.15	3.01	.11	13.54
	3	16.78	17.43	0	0	.21	.35	.07	.78	.64	.41	3.52	0	11.45
	4	8.33	8.45	0	0	0	0	0	0	0	0	.03	0	8.42
	Sum		*71.82*	*2.90*	*2.23*	*.27*	*.60*	*3.85*	*1.16*	*1.54*	*15.66*	*6.56*	*.11*	*36.94*
							Tree diameter class: 38 cm							
Pre-epidemic	0	82.56	0	0	0	0	0	0	0	0	0	0	0	0
	1	69.98	12.58	.41	.50	.03	0	1.14	1.73	0	.24	0	0	8.53
	2	40.36	29.62	1.30	.08	0	0	1.90	0	.25	9.86	.07	0	16.16
	3	16.96	23.40	.30	2.46	.01	.14	.42	0	.30	4.88	.08	0	14.81
	4	8.25	8.71	0	0	0	0	0	0	0	0	0	0	8.71
	Sum		*74.31*	*2.01*	*3.04*	*.04*	*.14*	*3.46*	*1.73*	*.55*	*14.98*	*.15*	*0*	*48.21*
Epidemic	0	128.88	0	0	0	0	0	0	0	0	0	0	0	0
	1	117.23	11.65	2.63	1.20	0	0	3.23	.15	.58	.48	0	0	3.38
	2	51.18	66.05	.78	7.78	0	0	1.70	1.38	.33	30.20	14.13	0	9.75
	3	26.30	24.88	0	0	.10	.15	.28	.15	.25	0	.03	0	23.92
	4	17.08	9.22	0	0	0	0	0	0	0	0	0	0	9.22
	Sum		*111.80*	*3.41*	*8.98*	*.10*	*.15*	*5.21*	*1.68*	*1.16*	*30.68*	*14.16*	*0*	*46.27*
Post-epidemic	0	100.20	0	0	0	0	0	0	0	0	0	0	0	0
	1	82.49	17.71	1.53	1.51	.04	0	6.73	0	0	2.84	0	0	5.05
	2	34.84	47.65	1.61	2.65	0	0	5.34	.35	.18	19.41	5.92	.04	12.15
	3	14.74	20.10	0	0	.04	.18	.41	.26	.05	.47	1.46	.05	17.18
	4	5.33	9.41	0	0	0	0	0	0	0	0	0	0	9.41
	Sum		*94.87*	*3.14*	*4.16*	*.09*	*.18*	*12.48*	*.61*	*.23*	*22.72*	*7.38*	*.09*	*43.79*

[1]Mortality factor abbreviations are defined in footnote 1, table 9

(con.)

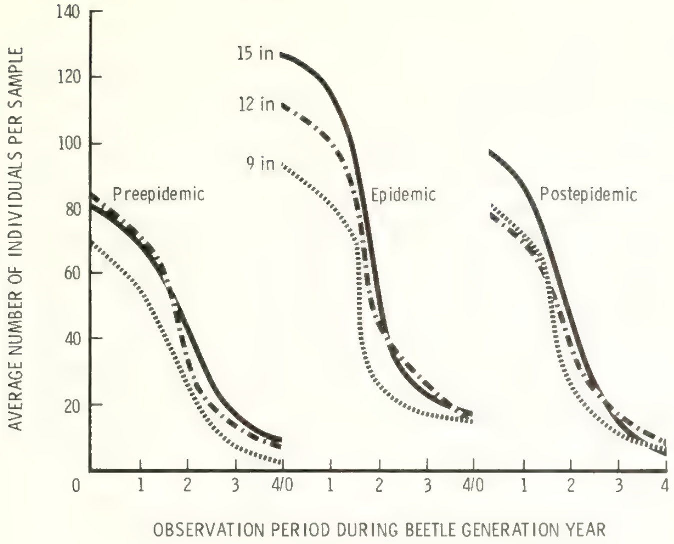

Figure 35.—Mountain pine beetle brood survival by observation, tree diameter class, and stage of infestation.

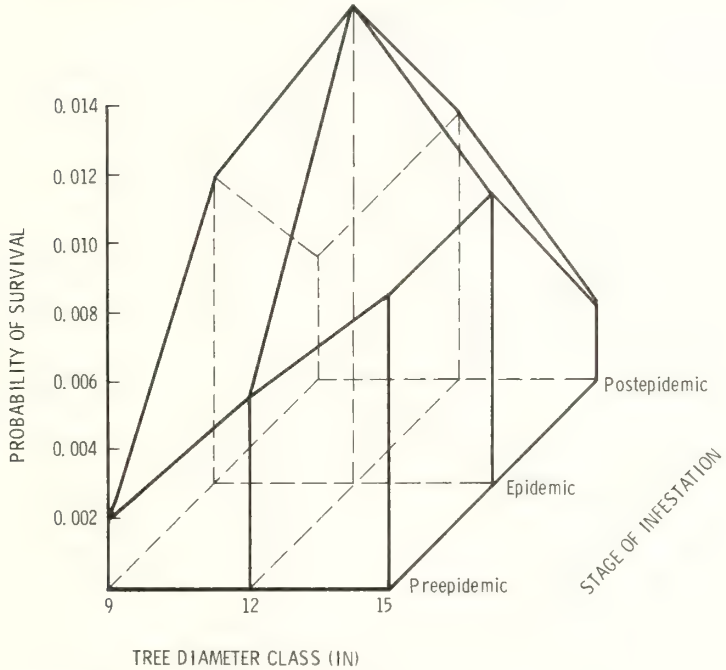

Figure 36.—Probability of any one mountain pine beetle egg surviving to the adult stage by tree diameter class and stage of infestation.

Table 12.—General probability of a mountain pine beetle surviving from egg to adult by lodgepole pine diameter class and stage of infestation

Stage of infestation	Tree diameter class		
	23 cm	30 cm	38 cm
Preepidemic	0.00196	0.00551	0.00850
Epidemic	.00900	.01403	.00850
Postepidemic	.00360	.00776	.00223

The greater survival in the 12-inch (30-cm) over the 15-inch (38-cm) class during the epidemic and postepidemic periods is probably that most of the large diameter trees have been killed, leaving only a few that may be of low quality. Residual trees within the 15-inch (38-cm) class may be slow growing and therefore provide a low amount of food (thin phloem) and moisture (thin sapwood) for beetle survival. These assumptions will be discussed more fully below.

Life Expectations.—Life table studies focus upon life expectation and survival rates. By comparing these, the intensity of risks during the stages of an infestation can be evaluated. The rate of survival (or conversely, mortality) governs life expectation. For the mountain pine beetle, the total life interval from egg to adult is approximately 365 days. The abridged life table for proportions of survival and death, life expectation, and the variances for both are given in table 13. When the cause of beetle death is not specified, the probabilities of survival and death and their variances become general probabilities.

Life expectations for mountain pine beetle populations fluctuate within diameter classes and within and among stages of infestations. However, life expectations generally increase from the smallest to the largest diameter tree class and are greatest during the epidemic stage (table 14 and fig. 37). Life expectations within the 12-inch (30-cm) diameter class appear consistent (table 14). Lack of variation in this class over the three infestation classes suggests that significant population changes that affect the beginning or end of an epidemic are not occurring within the 12-inch (30-cm) class. It is in the 9- and 15-inch (23- and 38-cm) classes where life expectations show considerable change and reflect infestation trend.

Table 13.—The abridged cohort life table and life expectations for mountain pine beetles in three lodgepole pine diameter classes and three stages of infestation

Infestation/tree diameter class	Interval length (days) x_i to x_{i+1}	Number live at start of x_i (l_i)	Number dying during x_i to x_{i+1} (d_i)	Surviving x_i to x_{i+1} (p_i)	Dying x_i to x_{i+1} (q_i)	Variance $(V_{p_i} V_{q_i})$	Fraction of last interval of life (a_i)	Life expectations observed at age x_i (e_i)	(Ve_i)	(SEe_i)
Pre-	30	69.64	14.27	0.795	0.205	0.00234	0.50	158.26	137.58	11.73
epidemic	180	55.37	25.01	.436	.564	.00444	.50	165.18	124.33	11.15
	60	30.36	22.15	.118	.882	.00343	.50	47.10	8.24	2.87
23 cm	30	8.21	4.88	.048	.952	.00557	.50	33.25	6.34	2.52
	60	3.33	3.33	0	1.000	—	—	30.00	—	—
	30	83.68	12.90	.856	.154	.00158	.50	163.01	107.11	10.35
	180	70.78	38.08	.391	.609	.00336	.50	159.99	90.67	9.52
30 cm	60	32.70	17.24	.185	.815	.00461	.50	61.49	19.33	4.40
	30	15.46	8.04	.089	.911	.00524	.50	36.60	7.21	2.69
	60	7.42	7.42	0	1.000	—	—	30.00	—	—
	30	82.56	12.58	.848	.152	.00156	.50	176.40	131.83	11.48
	180	69.98	29.62	.489	.511	.00357	.50	175.42	115.54	10.75
38 cm	60	40.36	23.40	.205	.795	.00404	.50	58.11	15.19	3.90
	30	16.96	8.71	.100	.900	.00531	.50	36.89	7.42	2.72
	60	8.25	8.25	0	1.000	—	—	30.00	—	—
Epidemic	30	93.60	7.82	.916	.084	.00082	.50	169.95	72.21	8.50
	180	85.78	58.40	.293	.707	.00241	.50	146.43	57.61	7.59
	60	27.38	8.03	.207	.793	.00600	.50	86.80	54.80	7.40
23 cm	30	19.35	4.14	.162	.838	.00702	.50	50.37	18.17	4.26
	60	15.21	15.21	0	1.000	—	—	30.00	—	—
	30	113.48	9.83	.913	.087	.00070	.50	181.14	82.90	9.10
	180	103.65	54.17	.436	.564	.00237	.50	166.90	71.68	8.47
30 cm	60	49.48	19.44	.265	.735	.00394	.50	71.09	22.26	4.72
	30	30.04	14.90	.133	.867	.00384	.50	37.68	5.60	2.37
	60	15.14	15.14	0	1.000	—	—	30.00	—	—
	30	128.88	11.65	.848	.152	.00100	.50	173.31	77.71	8.82
	180	117.23	66.05	.489	.511	.00213	.50	159.04	57.41	7.58
38 cm	60	51.18	24.88	.205	.795	.00318	.50	68.15	16.79	4.10
	30	26.30	9.22	.100	.900	.00342	.50	44.22	6.84	2.62
	60	17.08	17.08	0	1.000	—	—	30.00	—	—
Post-	30	80.43	10.47	.870	.130	.00141	.50	159.01	93.76	9.68
epidemic	180	69.96	43.12	.334	.666	.00318	.50	150.56	76.51	8.75
	60	26.84	13.60	.165	.835	.00513	.50	67.85	26.81	5.18
23 cm	30	13.24	17.24	.075	.925	.00524	.50	46.72	11.68	3.42
	60	6.00	6.00	0	1.000	—	—	30.00	—	—
	30	80.15	13.16	.836	.164	.00171	.50	168.08	125.01	11.18
	180	66.99	32.78	.427	.573	.00365	.50	168.14	109.39	10.46
30 cm	60	34.21	17.43	.209	.791	.00483	.50	63.03	21.41	4.63
	30	16.78	8.45	.104	.896	.00555	.50	37.34	7.95	2.82
	60	8.33	8.33	0	1.000	—	—	30.00	—	—
	30	100.20	17.71	.823	.177	.00145	.50	152.18	77.16	8.78
	180	82.49	47.65	.348	.652	.00275	.50	151.63	63.64	7.98
38 cm	60	34.84	20.10	.147	.853	.00360	.50	55.92	12.08	3.47
	30	14.74	9.40	.053	.947	.00341	.50	31.26	3.44	1.85
	60	5.33	5.33	0	1.000	—	—	30.00	—	—

Table 14.—The observed life expectation for mountain pine beetles (e_i) at age x_i in three lodgepole pine diameter classes and three stages of infestation

Stage of infestation	Observation (age x_i)	Tree diameter class 23 cm	30 cm	38 cm
Preepidemic	0	158.26	163.01	176.40
	1	165.18	159.99	175.42
	2	47.10	61.49	58.11
	3	33.25	36.60	36.89
	4	30.00	30.00	30.00
Epidemic	0	169.95	181.14	173.31
	1	146.43	166.90	159.04
	2	86.80	71.09	68.14
	3	50.37	37.68	44.22
	4	30.00	30.00	30.00
Postepidemic	0	159.01	168.08	152.18
	1	150.56	168.14	151.63
	2	67.85	63.03	55.92
	3	46.72	37.34	31.26
	4	30.00	30.00	30.00

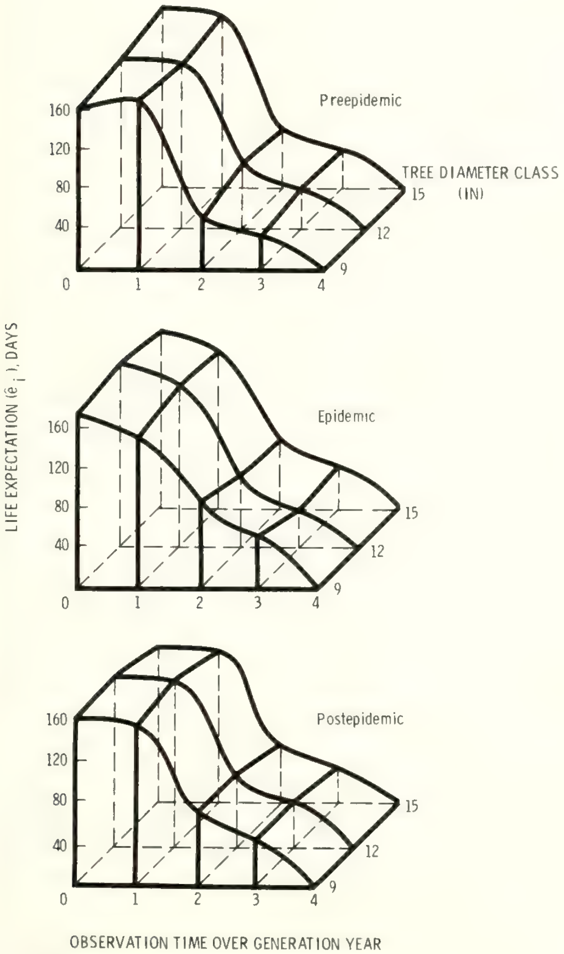

Figure 37.—Life expectations for mountain pine beetles in days at each observed time during the generation year by tree diameter class and stage of infestation.

During the preepidemic period, the greatest beetle life expectations occur in large diameter trees; during epidemic and postepidemic periods, life expectations are greatest within the smallest diameter class. When they do occur, changes in life expectation ($\hat{e}_i$) are probably associated with shifts in the attack and gallery densities of the beetle by diameter over the life of an infestation. During the early years, attack density declines, then begins to increase as the infestation progresses (fig. 38) (Cole and others 1976; Klein and others 1978). During the postepidemic period in particular, minimal numbers of large diameter trees remain, and these are infested at denser rates than those earlier in the infestation, resulting in low brood production.

General probability of survival.—The general probability of survival from egg to adult follows the configuration of life expectations (table 15; fig. 39). During the preepidemic period, the general probability of survival increases over diameter class within each brood developmental period. These probabilities shift slightly in favor of the 12-inch (30-cm) diameter class during the epidemic and increase strongly for it during the postepidemic stage. The greater survival in 15-inch (38-cm) trees in the preepidemic stage suggests these trees provide the impetus for an epidemic.

Within diameter class, over stage of infestation, the probability of survival generally peaks, as expected, during the epidemic. Survival is greater during the postepidemic than during the preepidemic in the 9-inch (23-cm) class, only slightly greater in the 12-inch (30-cm), but less in the 15-inch (38-cm) (fig. 40). The lower survival in large trees during the postepidemic is probably due to the large increase in attack and gallery densities in the 15-inch (38-cm) d.b.h. class.

Table 15.—General probabiilties of mountain pine beetles surviving the growth interval, x_i to x_{i+1}, in three lodgepole pine diameter classes and three stages of infestation

Stage of infestation	Interval (x_i to x_{i+1})		Tree diameter class 23 cm	30 cm	38 cm
		Days			
Preepidemic	0.	30	0.795	0.856	0.848
	1.	180	.436	.391	.489
	2.	60	.118	.185	.205
	3.	30	.048	.089	.100
	4.	60	0	0	0
Epidemic	0.	30	.916	.913	.848
	1.	180	.293	.436	.489
	2.	60	.207	.265	.205
	3.	30	.162	.133	.100
	4.	60	0	0	0
Postepidemic	0.	30	.870	.836	.823
	1.	180	.334	.427	.348
	2.	60	.165	.209	.147
	3.	30	.075	.104	.053
	4.	60	0	0	0

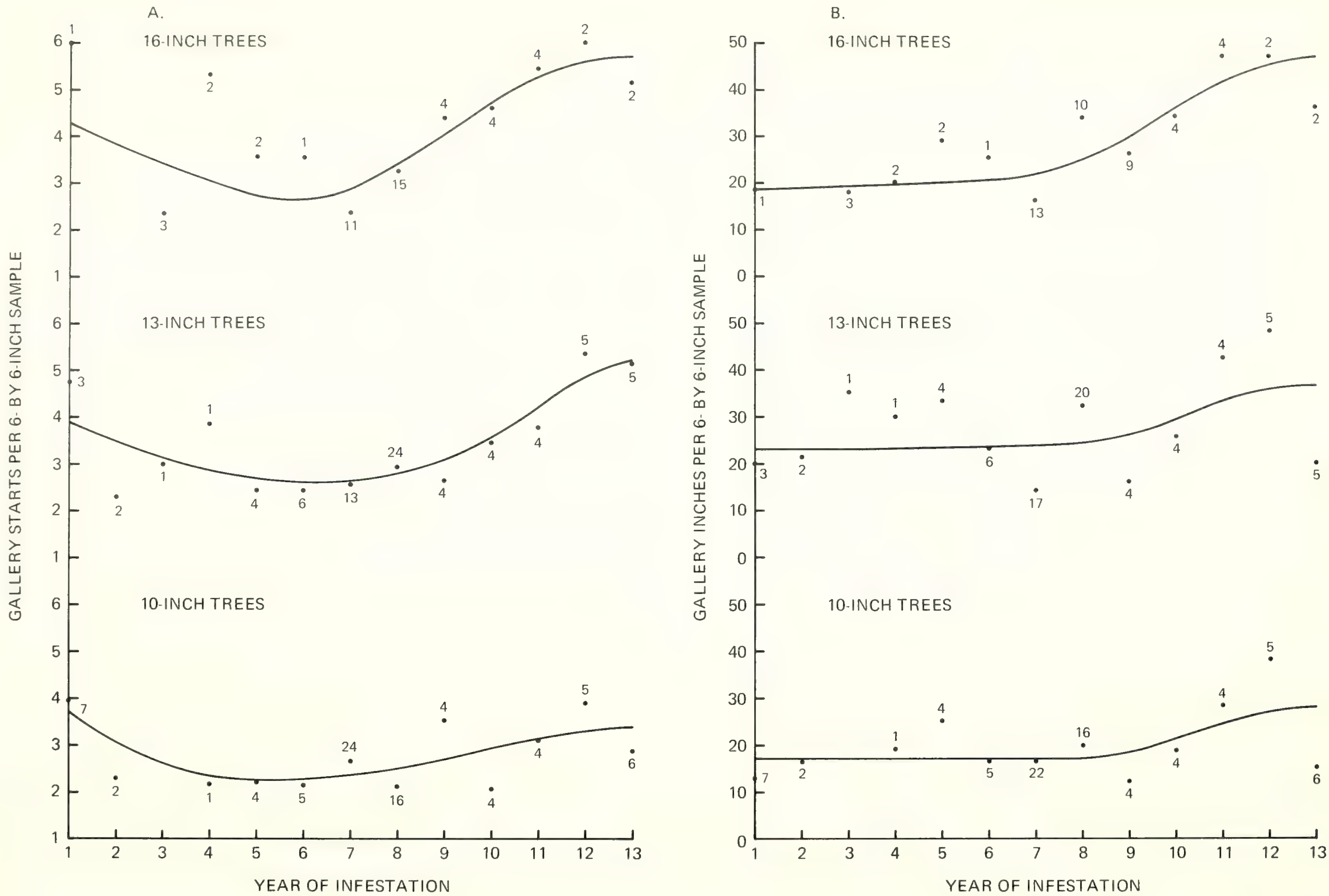

Figure 38.—Mountain pine beetle egg gallery starts and egg gallery inches by diameter for 13 years. A. Egg gallery starts; B. egg gallery inches. Number at each data point indicates number of trees sampled (Cole and others 1976).

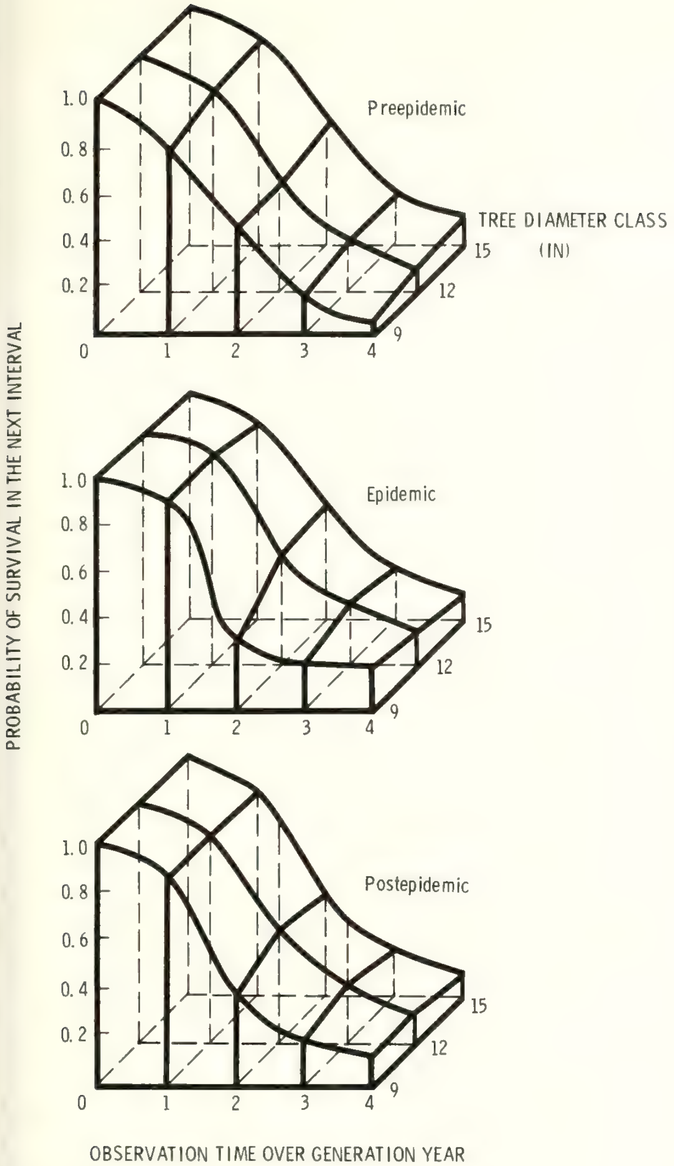

Figure 39.—Probability of mountain pine beetle survival to the next interval by tree diameter class and stage of infestation.

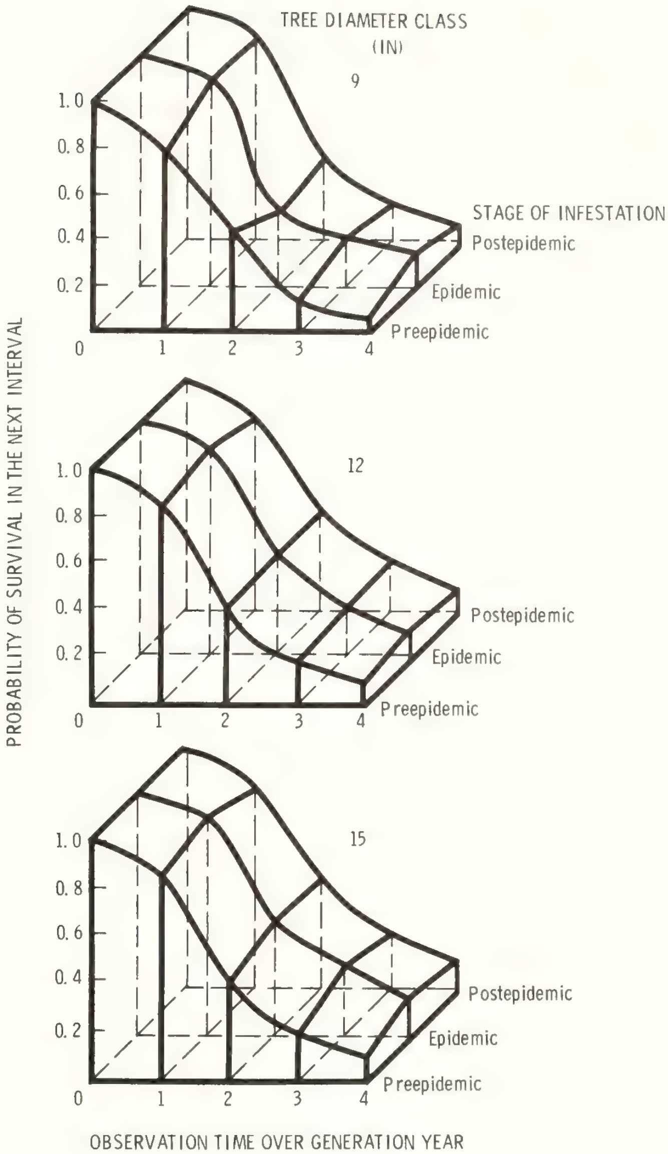

Figure 40.—Probability of mountain pine beetle survival to the next interval by stage of infestation and tree diameter class.

Crude probability of death.—General mortality is the total mortality at a particular time. The component probabilities of death (crude probabilities) to specific mortality factors are additive to the sum of the general mortality. The greatest cause of mortality is listed as "unknown," which accounted for approximately 50 percent of mortality during any beetle generation, within any diameter class of trees, and during any infestation stage (fig. 41). If the causes were known, unknown mortality probably would be proportionally distributed among the other causes according to their respective occurrence. However, in interpreting the following analyses, mortality will be evaluated as originally recorded.

The crude probabilities of death due to specific mortality factors are shown in table 16 and figure 42. The general probability of death is the rear profile in each case. Smoothed curves have been drawn through mortality estimates for discrete points in time to facilitate visual appraisal of mortality trends over time. Mortality read from these graphs, however, is only pertinent at that particular time.

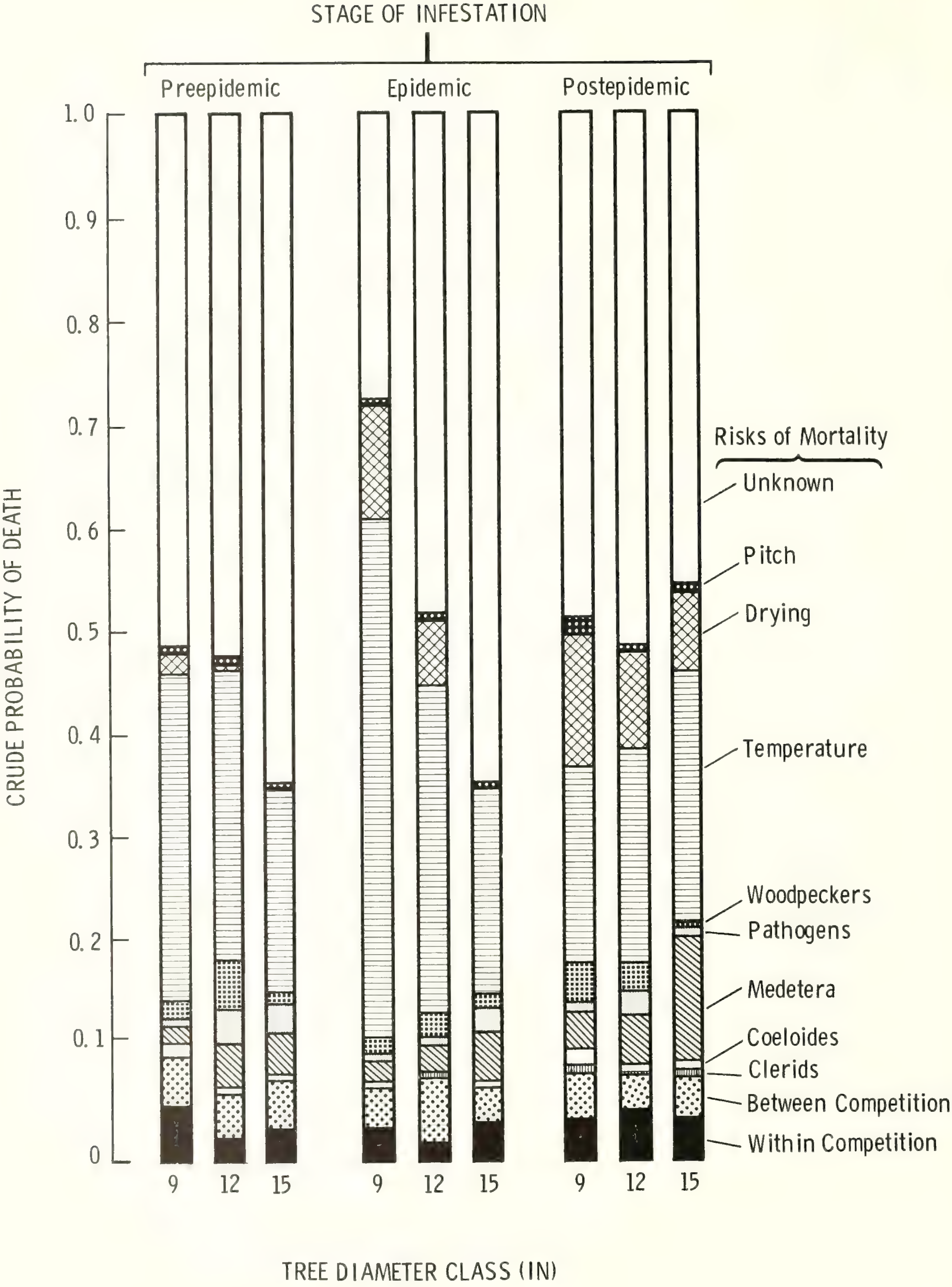

Figure 41.—Crude probability of mountain pine beetle death by specific mortality factors in three lodgepole pine diameter classes.

Table 16.—Crude probability of mountain pine beetle death due to a specific mortality factor[1] in the presence of all other mortality factors by lodgepole pine diameter class and stage of beetle infestation

Stage of infestation	Observations	General probability		Crude probabilities										
		Survival	Death	WC	BC	CL	CD	MD	PA	WP	T	D	PI	UNK
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	1	.795	.205	.077	.076	0	0	.018	0	0	.018	0	0	.811
epidemic	2	.436	.564	.049	.050	.001	0	.028	0	.023	.551	.040	0	.258
23 cm	3	.118	.882	.032	.050	.001	.016	.012	.018	.028	.319	.014	.005	.506
	4	.048	.952	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.046	.052	.001	.005	.018	.006	.018	.318	.020	.002	.514
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.856	.154	.026	.045	0	.002	.086	.065	0	.002	0	0	.774
30 cm	2	.391	.609	.013	.053	0	0	.035	.007	.061	.403	.009	.004	.415
	3	.185	.815	.032	.026	.002	.021	.050	.058	.091	.356	.004	0	.360
	4	.089	.911	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.018	.039	.001	.005	.044	.028	.051	.282	.006	.002	.525
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.848	.152	.033	.040	.002	0	.091	.137	0	.019	0	0	.678
38 cm	2	.489	.511	.044	.003	0	0	.064	0	.008	.333	.002	0	.546
	3	.205	.795	.013	.105	.001	.006	.018	0	.013	.209	.003	0	.633
	4	.100	.900	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.027	.041	.001	.002	.047	.023	.007	.202	.002	0	.649
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
Epidemic	1	.916	.084	.096	.093	0	0	.061	0	.013	.132	0	.026	.579
	2	.293	.707	.022	.040	0	0	.007	.001	.020	.634	.147	0	.129
23 cm	3	.207	.793	.019	.044	.004	.037	.016	.022	.025	.021	.083	.004	.725
	4	.162	.838	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.028	.044	.001	.004	.013	.003	.018	.448	.118	.003	.281
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.913	.087	.166	.214	0	0	.168	0	.023	.129	0	.015	.285
30 cm	2	.436	.564	0	.060	0	0	.008	.013	.025	.550	.124	0	.220
	3	.265	.735	0	0	.005	.024	.008	.003	.035	.005	.048	0	.872
	4	.133	.867	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.017	.055	.001	.005	.023	.008	.023	.317	.078	.001	.472
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.848	.152	.033	.040	.002	0	.091	.137	0	.019	0	0	.678
38 cm	2	.489	.511	.044	.003	0	0	.064	0	.008	.333	.002	0	.546
	3	.205	.795	.013	.105	.001	.006	.018	0	.013	.209	.003	0	.633
	4	.100	.900	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.027	.041	.001	.002	.047	.023	.007	.202	.002	0	.649
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
Post-	1	.870	.130	.188	.282	.014	.003	.176	.019	.003	.202	.011	.031	.071
epidemic	2	.334	.666	.005	.020	.001	.001	.020	.003	.038	.287	.111	.010	.505
	3	.165	.835	0	0	.006	.079	.004	.006	.046	.034	.319	.001	.505
23 cm	4	.075	.925	0	0	0	.003	0	.003	0	0	.010	0	.984
Crude probability per generation				.029	.051	.004	.015	.037	.006	.031	.201	.125	.011	.490
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.836	.164	.190	.117	.002	.006	.160	.008	.014	.236	0	0	.267
30 cm	2	.427	.573	.012	.021	.001	.005	.051	.009	.022	.371	.092	.003	.413
	3	.209	.791	0	0	.012	.020	.004	.045	.037	.024	.202	0	.656
	4	.104	.896	0	0	0	0	0	0	0	0	.004	0	.996
Crude probability per generation				.040	.031	.004	.008	.054	.016	.021	.218	.091	.002	.515
	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.823	.177	.086	.085	.003	0	.038	0	0	.160	0	0	.286
38 cm	2	.348	.652	.034	.056	0	0	.112	.007	.004	.407	.124	.001	.255
	3	.147	.853	0	0	.002	.009	.020	.013	.002	.023	.073	.003	.855
	4	.053	.947	0	0	0	0	0	0	0	0	0	0	1.000
Crude probability per generation				.033	.044	.001	.002	.132	.006	.002	.240	.078	.001	.461

[1]Mortality factor abbreviations are defined in footnote 1, table 9.

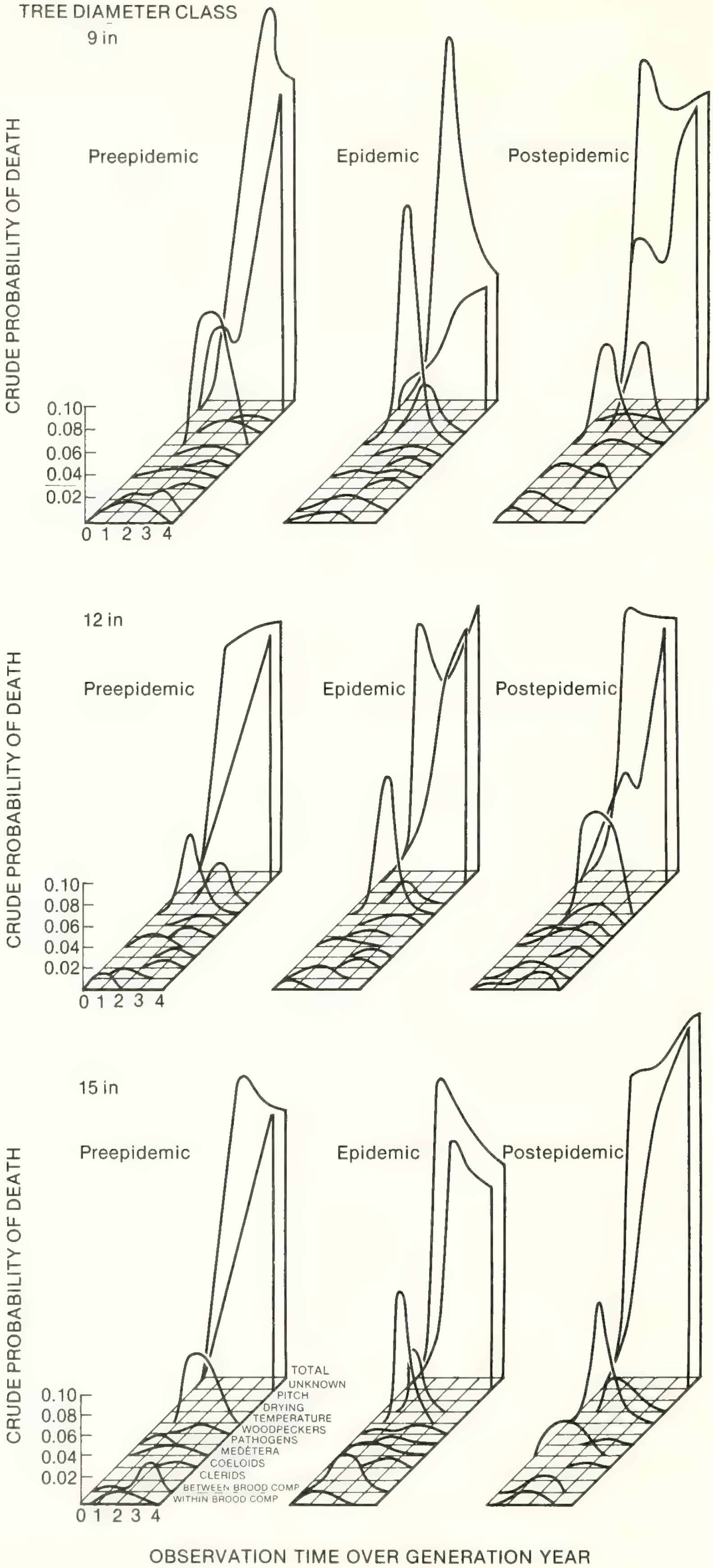

Figure 42.—Graphic display of crude probability of mountain pine beetle death from specific mortality factors by tree diameter class, stage of infestation, and observation.

These data support previous studies (Cole 1974, 1975) showing that winter temperatures followed by drying of phloem in the early summer are the two major causes of mountain pine beetle brood mortality. These factors decrease as diameter increases. Losses to temperature were highest during the epidemic except in the 15-inch (38-cm) class where they were slightly higher in the postepidemic. Losses to drying showed a steady increase with stage of infestation, probably reflecting increases in egg gallery density.

Specific mortality factors.—Within competition (WC) decreased with increased diameter during the preepidemic stage of infestation, but was higher in the 12-inch (30-cm) than the other two diameter classes during the epidemic stage. Within competition, although higher in the postepidemic than in earlier infestation stages, tended to decrease with increased tree diameter (fig. 43). Between competition (BC) followed somewhat the same pattern as within competition (fig. 44). Combining the effects of these two forms of competition, or crowding, an increase generally occurs from preepidemic to postepidemic stages (fig. 45). This increase is large in the 9-inch (23-cm) class. The 12-inch (30-cm) class also shows a large increase in both epidemic and postepidemic phases, with losses to competition slightly higher during the epidemic phase. These increases are probably related to the increased egg gallery densities as infestations progress (Cole and others 1976). Very little increase in mortality to competition occurs in the 15-inch (38-cm) class, probably because the thick phloem that usually occurs in large trees generally provides adequate space and food for the larvae.

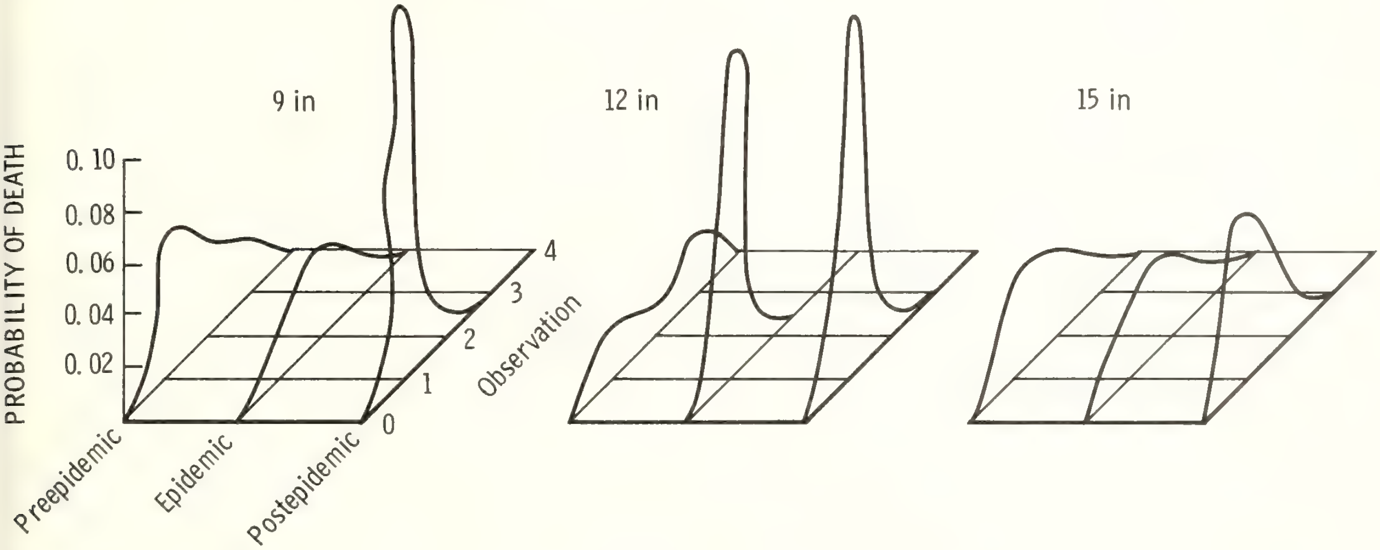

Figure 43.—Crude probability of mountain pine beetle death due to within competition by tree diameter class and stage of infestation.

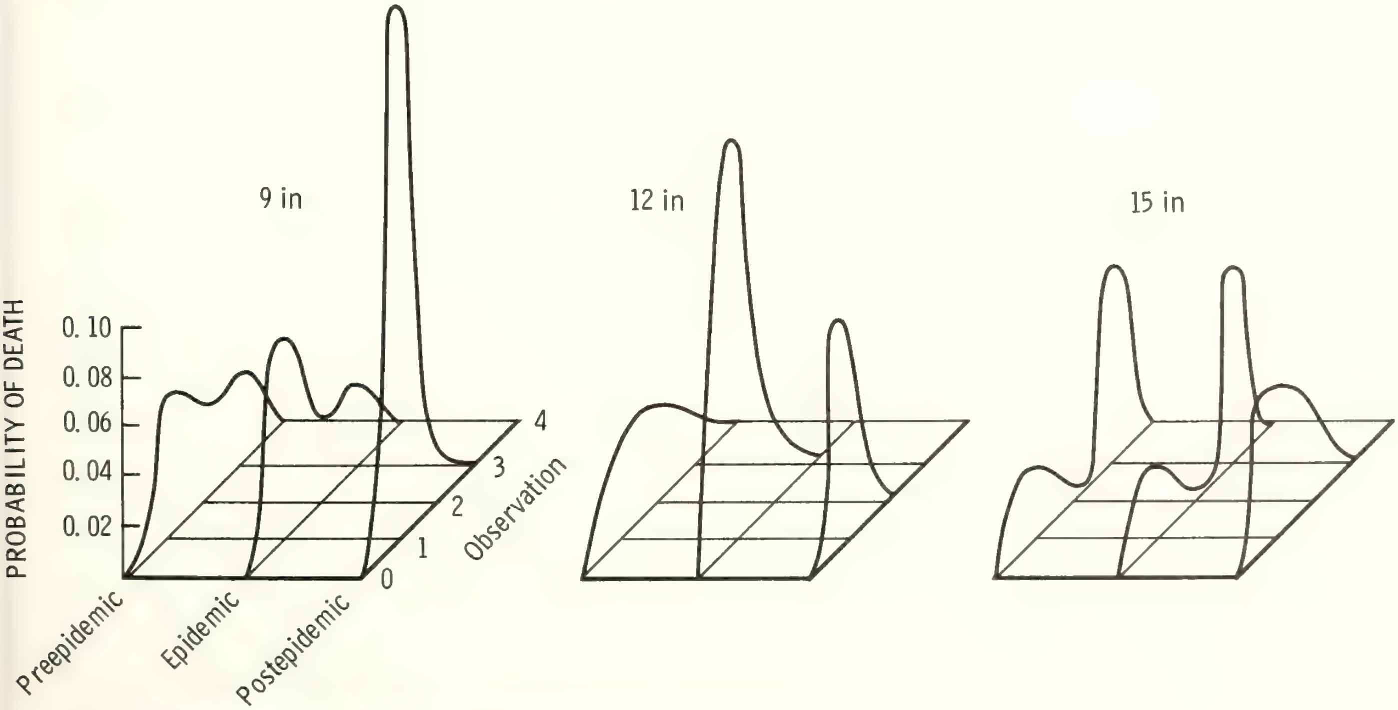

Figure 44.—Crude probability of mountain pine beetle death due to between competition by tree diameter class and stage of infestation.

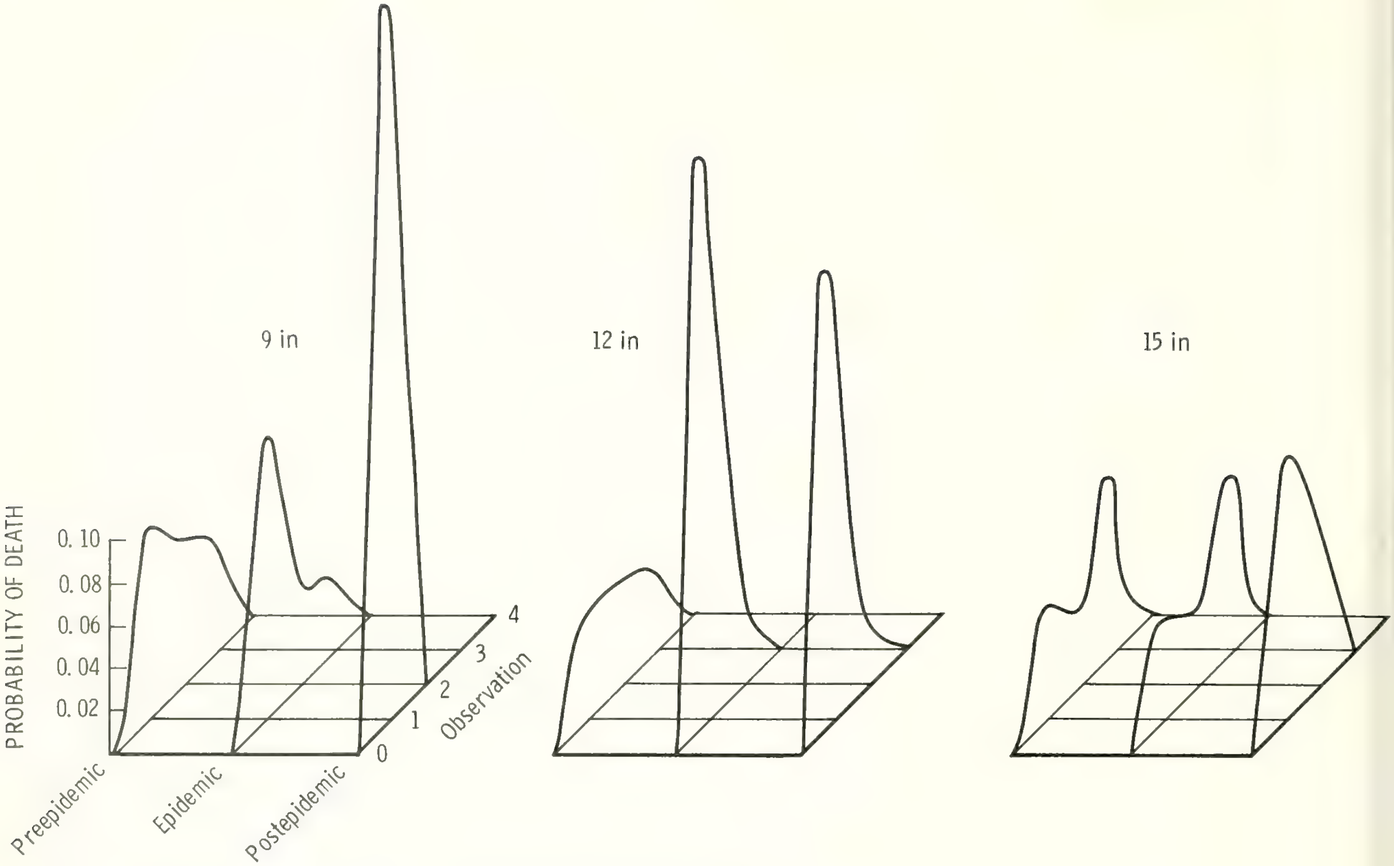

Figure 45.—Combined crude probability of mountain pine beetle death from within and between competition by tree diameter class and stage of infestation.

Medetera aldrichii showed a density-dependent response over time (fig. 46). *Medetera* not only increased by stage of infestation but also showed preference for the greater beetle populations by diameter class. Because of this response and its magnitude, *Medetera* appears to be the most important of the insect predators and parasites of mountain pine beetles. *Medetera* probably is a significant factor in altering expected beetle production from large diameter trees during the postepidemic period.

The probability of a mountain pine beetle being killed by clerids (*Thanasimus undatulus* and *Enoclerus sphegeus*) was extremely small and appears not to significantly reduce mountain pine beetle populations in lodgepole pine (fig. 47).

Probability of death by *Coeloides dendroctoni* also showed a density dependent response from preepidemic to postepidemic infestations in the 9-inch (23-cm) diameter trees (fig. 48). The increased parasitism by *Coeloides* in small diameter trees is probably due to the thin bark. Thick bark restricts parasitism by *Coeloides*, because *Coeloides*'s ovipositor is too short to reach the larvae under the bark.

Death due to woodpeckers showed a low density dependent response in the 9-inch (23-cm) trees and an inverse density dependent response in the 12-inch (30-cm). Probability of death increased over stage of infestation in the 9-inch (23-cm) trees and decreased in the 12-inch (30-cm). Woodpecker predation remained low with slight decrease in the 15-inch (38-cm) trees (fig. 49). The continual low amount of predation in the 15-inch (38-cm) trees was probably related to bark thickness, with greater effort required to remove larvae from thick than from thin bark. The greatest woodpecker predation occurred during the preepidemic stage and in the 12-inch (30-cm) class. During the preepidemic, few infested trees exist, and the woodpecker population is concentrated on these few trees. However, as the beetle population becomes epidemic, the woodpecker population, which does not increase proportionally to the beetle population, consumes proportionally less of the beetle population. The beetle population may still be too high in the postepidemic stage for woodpeckers to consume proportionally as many as in the preepidemic; however, an increase is evident in the 9-inch (23-cm) tree class.

Freezing temperatures were the greatest single cause of mountain pine beetle mortality (fig. 50). The evident peaks of probability of death during the epidemic stage of infestation were probably due to somewhat lower temperatures during that stage rather than to beetle population level. However, probability of death due to temperature was inversely related to increasing diameter in the preepidemic and epidemic stages, and directly related to increasing diameter in the postepidemic stage.

Probability of death due to desiccation caused by phloem drying increased over stage of infestation within each diameter class. Death due to drying, however, decreased with increased tree diameter (fig. 51). The increase in beetle losses to desiccation over the infestation is probably related to increased attack and egg gallery densities (Cole and others 1976), which open up the bark to more rapid drying. The inverse relation of probability of death to drying and tree diameter probably is at least partially related to quantity of moisture as indicated by sapwood thickness, which is positively related to diameter (Amman 1978).

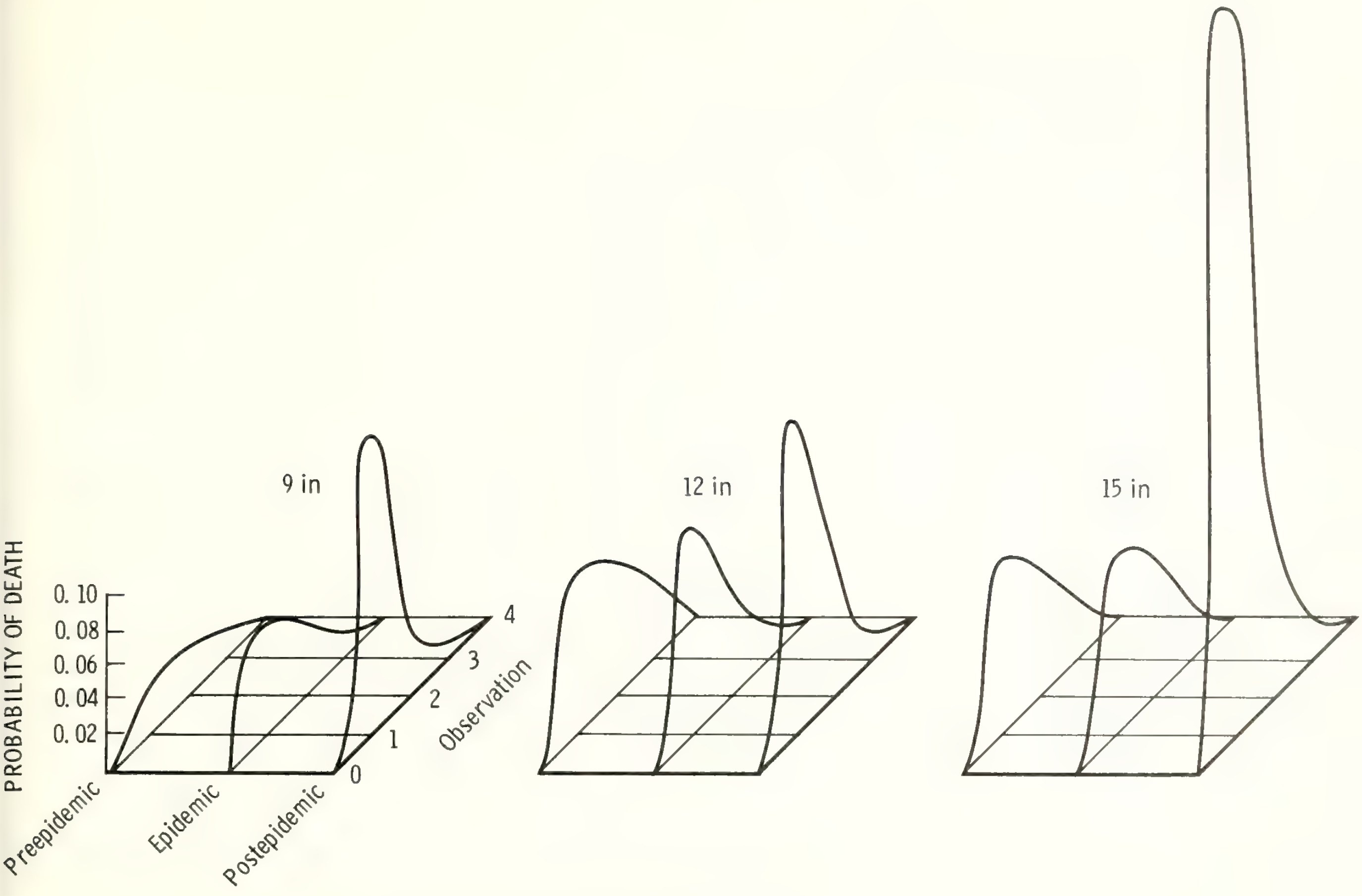

Figure 46.—Crude probability of mountain pine beetle death from *Medetera aldrichii* by tree diameter class and stage of infestation.

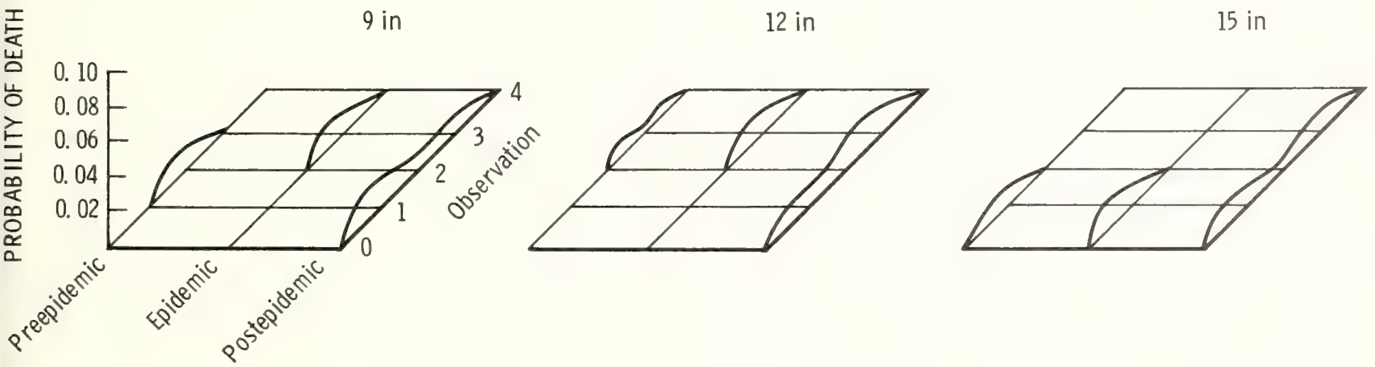

Figure 47.—Crude probability of mountain pine beetle death from clerids by tree diameter class and stage of infestation.

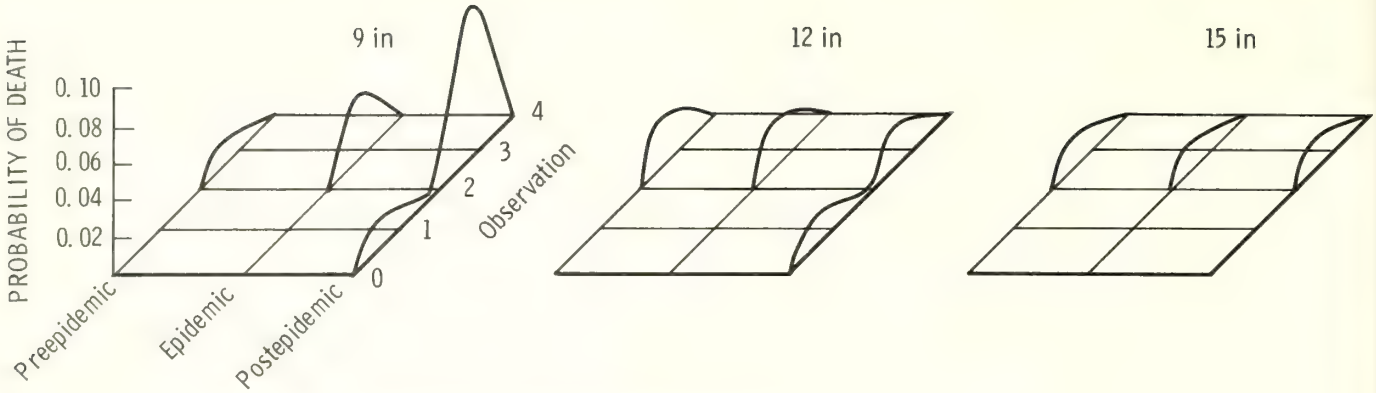

Figure 48.—Crude probability of mountain pine beetle death from *Coeloides dendroctoni* by tree diameter class and stage of infestation.

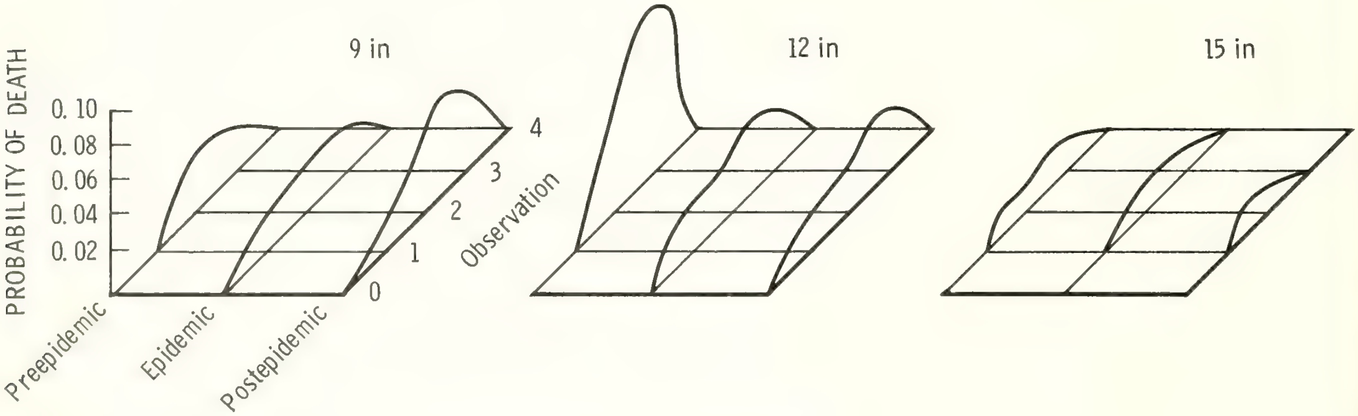

Figure 49.—Crude probability of mountain pine beetle death from woodpeckers by tree diameter class and stage of infestation.

Survival from egg to adult was highest in the 12-inch (30-cm) diameter tree class. However, survival was only 1.4 percent, and that occurred during the epidemic stage. Survival in the 9- and 15-inch (23- and 38-cm) classes was less than 1 percent. These survival rates suggest, first, that approximately 0.5 percent difference in survival separates increasing from static or decreasing populations. However, percentages do not reflect population numbers. Second, the mountain pine beetle is synchronized so closely with stand development and growth that the increased food supply, as a contributor to population explosion, probably far outweighs the concurrent influence of population reduction by biological and physical factors of mortality.

A special case.—The Logan Canyon plot on the Wasatch-Cache National Forest in northeastern Utah illustrates some discussion points. The mountain pine beetle has been at a "high endemic" level in this area for 9 years, based on rate of tree mortality and beetle survival rates. If certain risks of mortality were to be density dependent or independent, or if a steady mountain pine beetle population was to provide an opportunity for these factors to increase, they should have done so in the Logan Canyon infestation.

In the Logan Canyon infestation, the probability of any one egg reaching the adult stage was 0.00358 for populations within the 9-inch (23-cm) diameter class, 0.00639 for the 12-inch (30-cm), and 0.00560 for the 15-inch (38-cm). These survival probabilities are between those presented for preepidemic and epidemic populations in other study areas (table 12), with the exception of the 15-inch (38-cm) class where survival was lower than the preepidemic stage in other study areas. Percent beetle survival for each tree class was 10.4 for the 9-inch (23-cm) trees, 10.5 for the 12-inch (30-cm), and 9.9 for the 15-inch (38-cm) (table 17). These survival rates fit between the preepidemic and epidemic survival rates observed for beetles in the other study areas (table 16). Therefore, an infestation designation of high endemic (between preepidemic and epidemic) appears appropriate. Percent survival for mountain pine

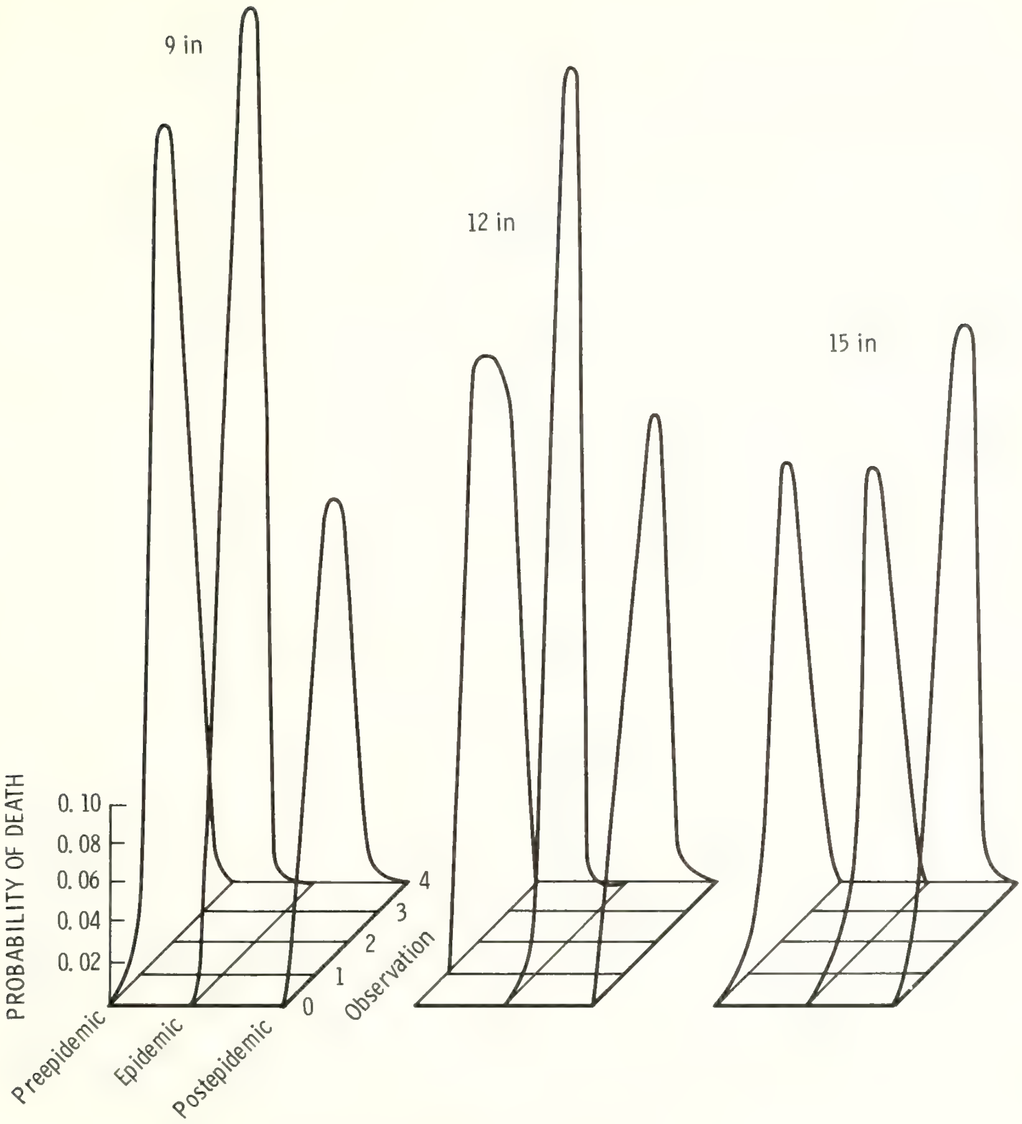

Figure 50.—Crude probability of mountain pine beetle death from winter temperatures by tree diameter class and stage of infestation.

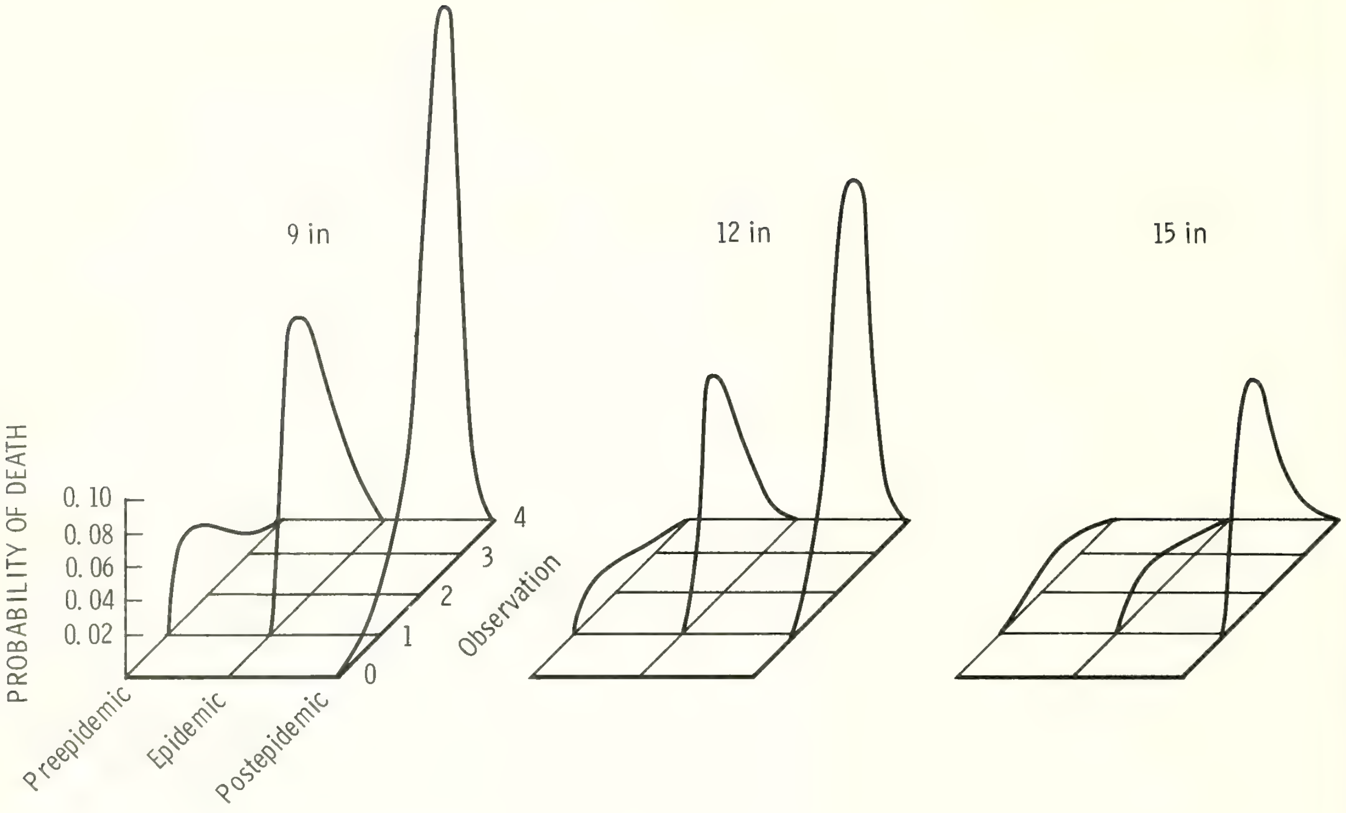

Figure 51.—Crude probability of mountain pine beetle death due to desiccation by tree diameter class and stage of infestation.

Table 17.—Crude probability of mountain pine beetle death due to a specific mortality factor[1] in the presence of all other mortality factors by lodgepole pine diameter class, Logan Canyon Plot, Wasatch-Cache National Forest

Tree diameter class	Observations	General probability		Crude probabilities										
		Survival	Death	WC	BC	CL	CD	MD	PA	WP	T	D	PI	UNK
23 cm	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.829	.171	.276	.251	.006	0	.103	.025	.011	.109	.002	.037	.180
	2	.315	.685	.006	.020	0	.001	.041	.001	.076	.387	.089	.001	.380
	3	.132	.868	.003	0	.003	.044	.010	.004	.001	.009	.189	.002	.735
	4	.104	.896	0	0	0	.117	0	0	.006	.008	.059	0	.310
Crude probability per generation				.057	.059	.002	.013	.045	.006	.056	.244	.092	.007	.419
30 cm	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.832	.168	.187	.131	0	0	.133	.037	.008	.187	.010	.031	.276
	2	.457	.543	.023	.055	0	.001	.078	.005	.077	.372	.056	.004	.330
	3	.160	.840	.004	.012	.007	.023	.012	.007	.039	.030	.108	.007	.751
	4	.105	.895	0	0	.004	.054	.004	0	0	0	.065	0	.873
Crude probability per generation				.046	.052	.002	.011	.062	.011	.047	.201	.065	.010	.493
38 cm	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
	1	.778	.222	.205	.308	0	0	.317	.009	0	.086	0	.011	.064
	2	.356	.644	.006	.033	0		.050	.001	.007	.307	.029	.012	.554
	3	.204	.796	.066	0	.006	.058	.036	.010	.038	.070	.149	0	.567
	4	.099	.901	0	0	0	.001	.019	0	0	0	.009	0	.972
Crude probability per generation				.065	.091	.001	.010	.110	.004	.010	.176	.040	.009	.484

[1]Mortality factor abbreviations are defined in footnote 1, table 9.

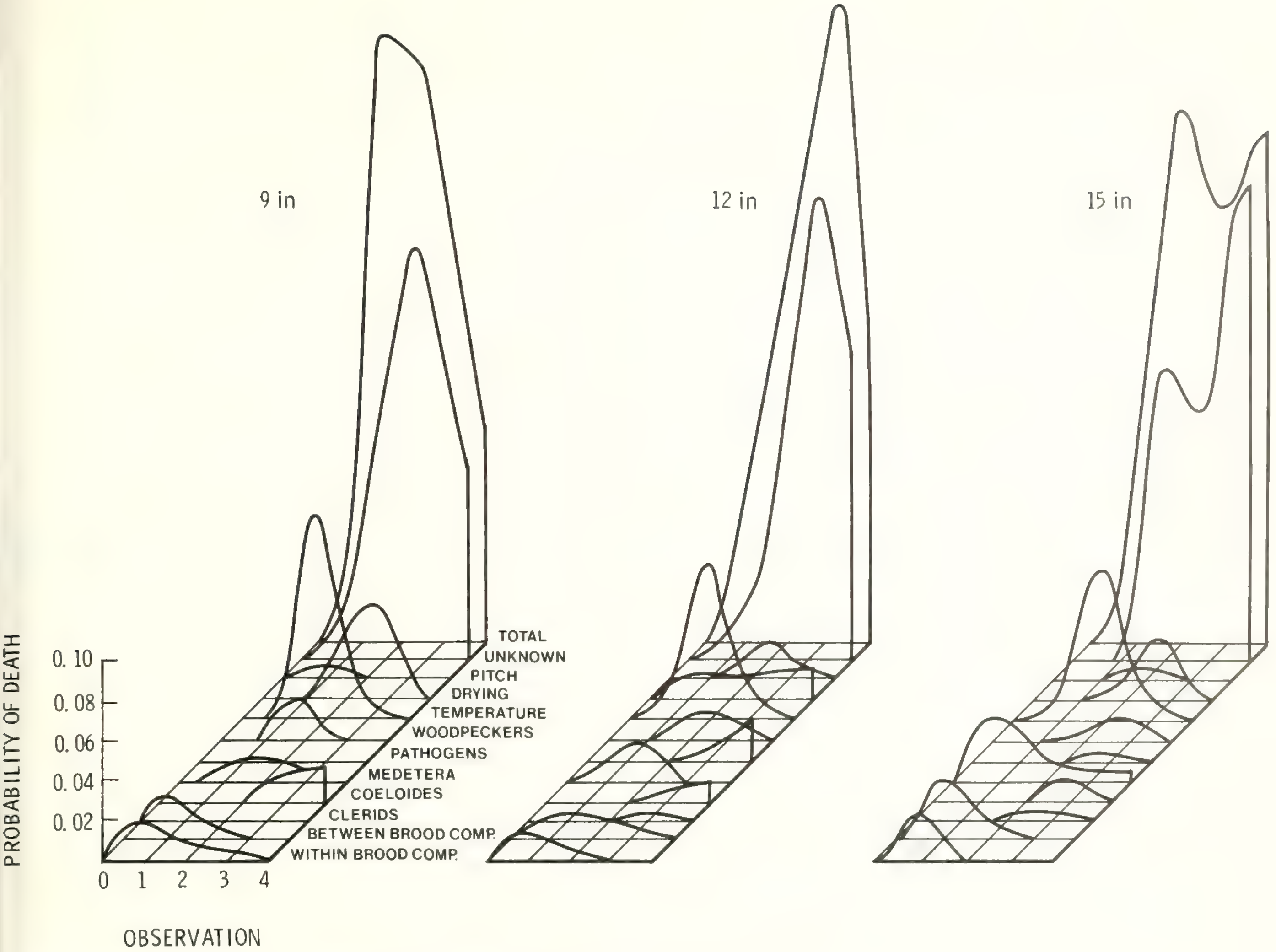

Figure 52.—Crude probability of mountain pine beetle death from specific factors in three diameter classes, Logan Canyon plot, Wasatch-Cache National Forest, Utah.

beetle populations in ponderosa pine in relation to population trend were: decreasing ≤ 1; static about 3; and increasing about 10 (Knight 1959). The higher rate of survival needed to maintain the static situation in lodgepole than in ponderosa pine suggests that large losses of beetles occur during the flight period.

The crude probabilities for each mortality factor show trends similar to those presented for the other study plots, but the magnitudes differ somewhat (table 17; fig. 52). Crude probabilities of survival show that within competition is greatest within the 9-inch (23-cm) class, while between competition is greatest within the 15-inch (38-cm). Combined, the greatest effect on population reduction from these two mortality factors is in the smallest and largest diameter classes (fig. 53).

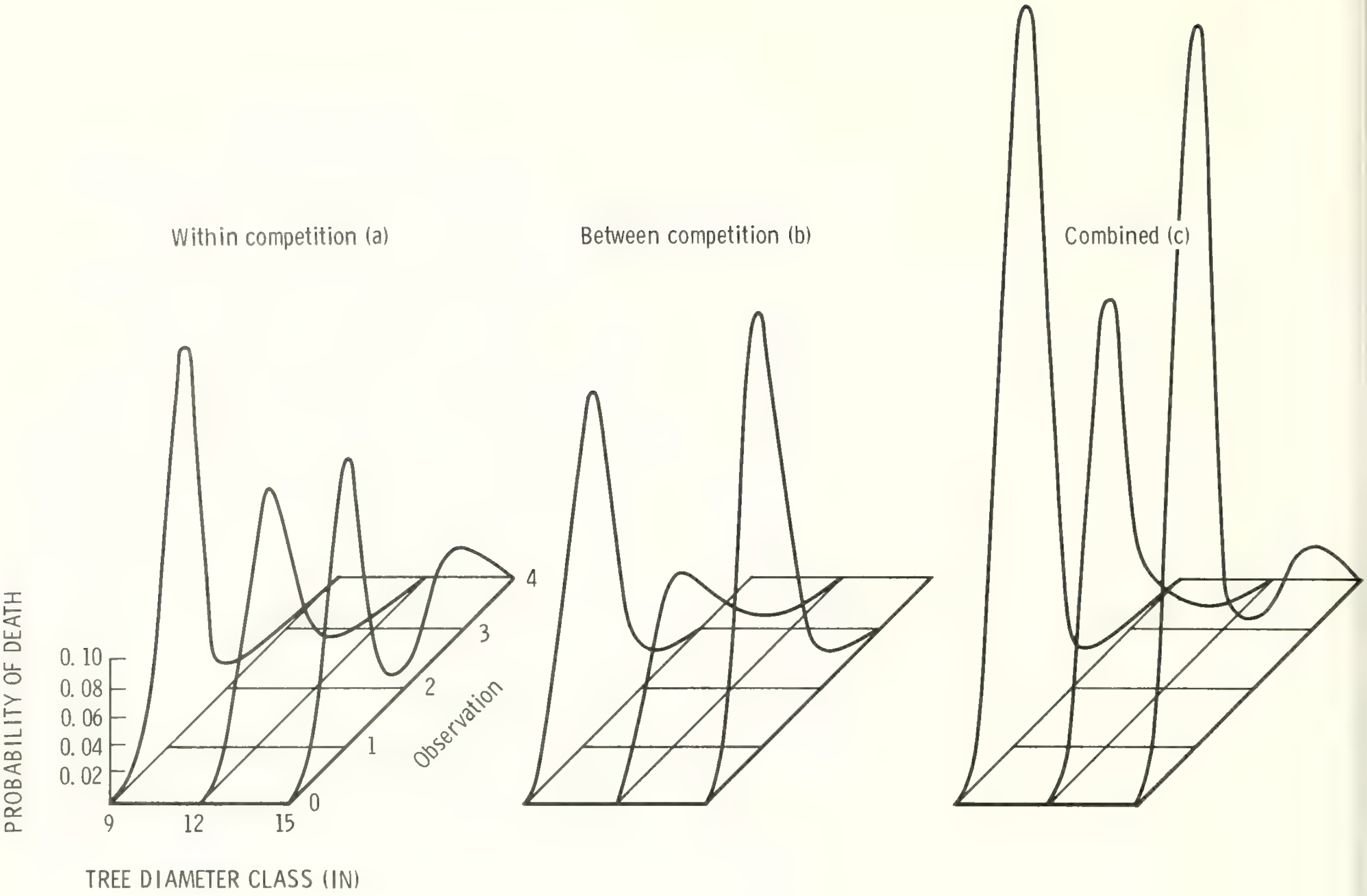

Figure 53.—Crude probability of mountain pine beetle death from within (a); between (b); and combined within-between competition (c), Logan Canyon plot, Wasatch-Cache National Forest, Utah.

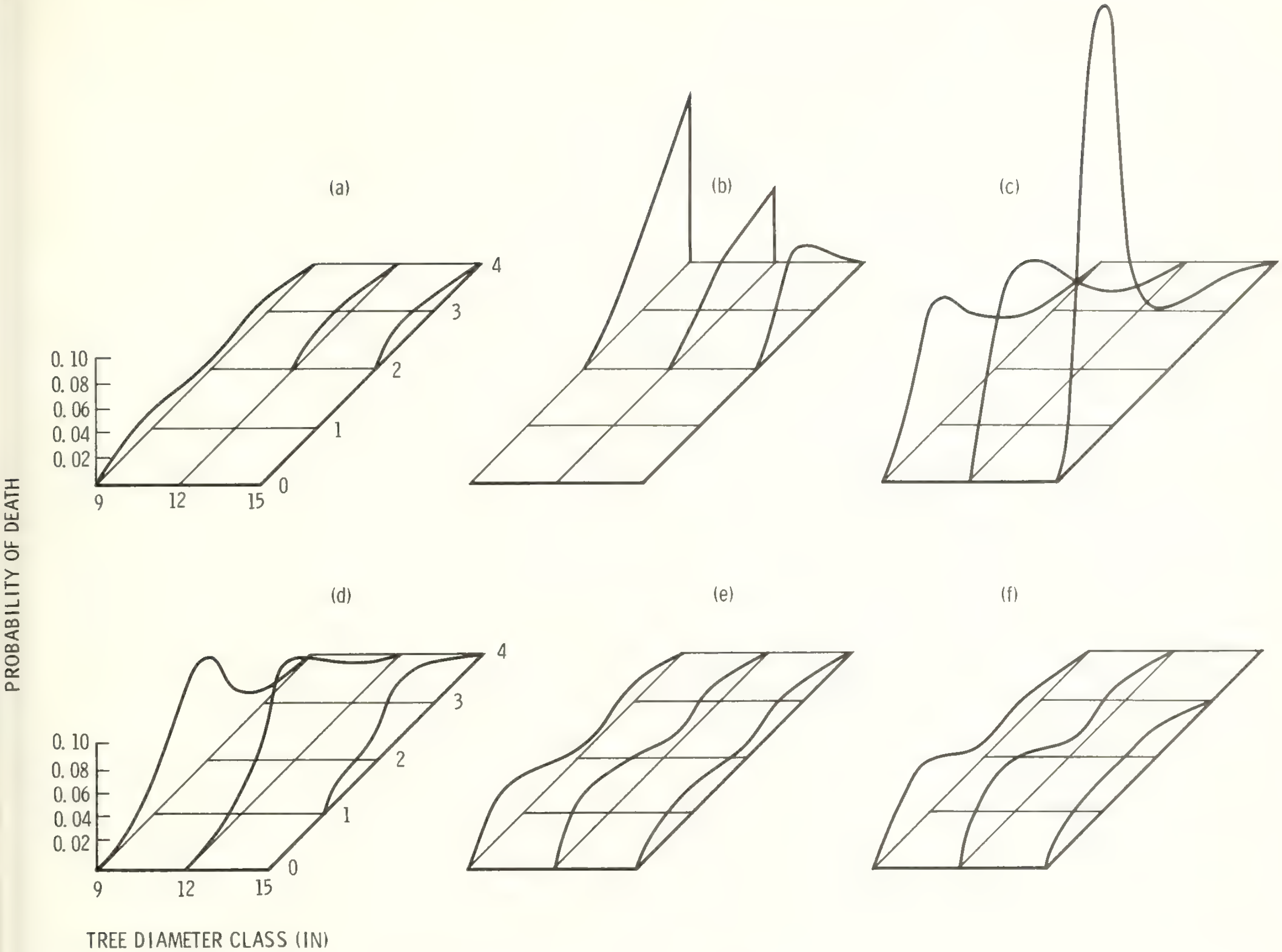

Figure 54.—Crude probability of mountain pine beetle death from clerids (a), *Coeloides* (b), *Medetera* (c), woodpeckers (d), pathogens (e), and pitch (f), Logan Canyon plot, Wasatch-Cache National Forest, Utah.

Probability of death from parasites, predators, pathogens, and pitch is approximately the same as in the other data sets. That is, clerids caused minor losses; *Coeloides* activity was greatest in the smallest diameter class and least in the largest diameter; *Medetera* showed some density dependence, with the greatest probability of predation occurring in the largest diameter class and least in the smallest; probability of death due to woodpeckers was greatest in the 9- and 12-inch (23- and 30-cm) classes; and losses to pathogens and pitch were greatest within the 9- and 12-inch (23- and 30-cm) classes during the fall (fig. 54). The 9- and 12-inch classes are more likely to sustain light attacks than the 15-inch (38-cm), resulting in resinosis and losses to pitch. Temperature and drying presented the greatest influence. Both followed the typical pattern by diameter class, having the greatest impact on beetles in small trees and least in large trees (fig. 55).

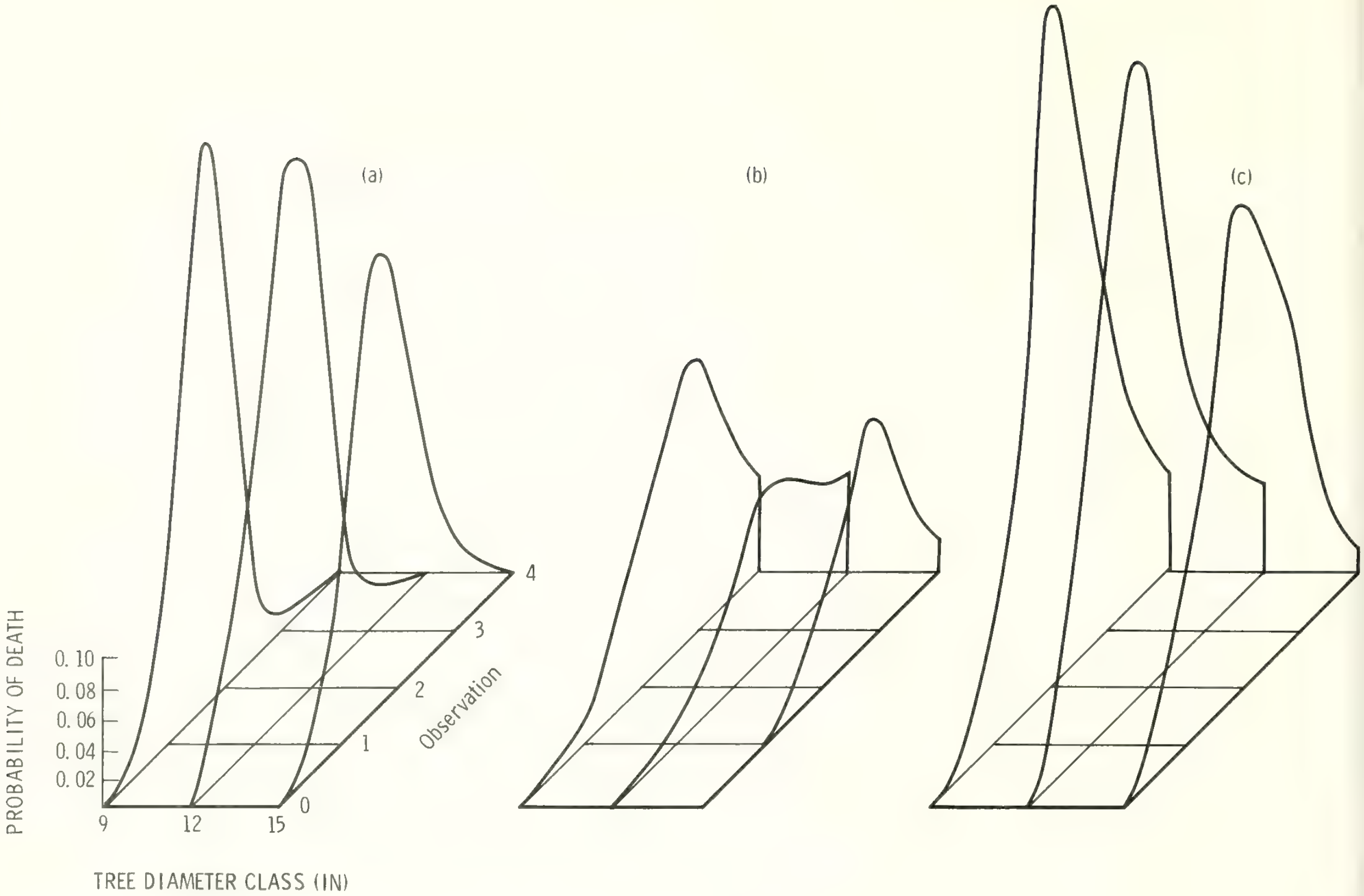

Figure 55.—Crude probability of mountain pine beetle death from winter temperatures (a), drying of phloem (b), and combined temperature-drying (c), Logan Canyon plot, Wasatch-Cache National Forest, Utah.

Probabilities of death due to individual factors in all plots suggest that none of the risks acting in the presence of other risks offers much, if any, regulatory influence upon a mountain pine beetle population. These observations further strengthen the hypothesis that mountain pine beetle populations are food-regulated (Cole and Amman 1969), and therefore are strongly dependent upon tree and stand conditions. The 15-inch (38-cm) trees appear to supply the impetus for starting epidemics, but because of their few numbers, these trees are eliminated early from the stand (Cole and Amman 1969; Klein and others 1978). Once the epidemic is well under way, brood survival in the 12-inch (30-cm) trees is sufficient to maintain the beetle population for several years into the postepidemic stage, when a large proportion of the infested trees are in the 9-inch (23-cm) class. However, the 9-inch (23-cm) trees at this infestation stage do not provide, on the average, adequate habitat for the beetle because of thin phloem and excessive drying. This results in greatly reduced survival. In addition, many beetles emigrate to other stands of trees (Klein and others 1978).

A SUMMARY OF HOST INFLUENCE

This section on biology and ecology of the mountain pine beetle demonstrates a number of beetle population characteristics associated with lodgepole pine size and associated characteristics. Small trees, on the average, have thin phloem of low quality and usually dry excessively during beetle development. Consequently, such trees generally produce low ratios of brood adults to parent adults. Beetles from small trees are small, appear to have slightly different genotype have sex ratios strongly skewed toward females, and show slow brood development. On the other hand, trees of large size usually have thick phloem of high quality and remain moist throughout beetle development. As a result, these trees generally produce high ratios of brood adults to parent adults. Beetles from large trees are large, have a genotype somewhat different from that of brood adults in small trees, have more even sex ratios, and are faster developing than beetles in small trees of thin phloem.

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APPENDIX
Regression Statistics for Figures

Figure 7.—Beetles (number/ft^2) as a function of emergence holes (number/ft^2).

$\hat{Y} = 0.308\ (X^{1.4});\ r = 0.85$

Figure 9.—Female beetles emerging (percent) as a function of emergence day (number).

$$
\begin{array}{lll}
 & & \text{Limits}\rightarrow \\
1974: & \hat{Y} = 59.3 - 0.375\ (7 - X)^{1.65} & 0 \le X \le 7 \\
 & \hat{Y} = 59.3 - 0.439\ (X - 7)^{1.4} & 7 < X \le 18
\end{array}
\left.\vphantom{\begin{array}{l}a\\b\\c\end{array}}\right\} r^2 = 0.042;\ P > 0.10
$$

$$
\begin{array}{lll}
1975: & \hat{Y} = 68.4 - 0.480\ (7 - X)^{1.65} & 0 \le X \le 7 \\
 & \hat{Y} = 68.4 - 0.669\ (X - 7)^{1.4} & 7 < X \le 18
\end{array}
\left.\vphantom{\begin{array}{l}a\\b\end{array}}\right\} r^2 = 0.518;\ P < 0.005
$$

Figure 11.—Beetle length (mm) as a function of emergence day (number).

Females 1974: $\hat{Y} = (X)\text{–}0.0371 + 5.3821;\ r^2 = 0.59;\ P < 0.005$

1975: $\hat{Y} = (X)\text{–}0.0162 + 5.0790;\ r^2 = 0.20;\ P < 0.100$

Males 1974: $\hat{Y} = (X)\text{–}0.0448 + 4.9255;\ r^2 = 0.54;\ P < 0.005$

1975: $\hat{Y} = (X)\text{–}0.0193 + 4.6755;\ r^2 = 0.46;\ P < 0.005$

Figure 13.—Female length (mm) as a function of egg gallery density (meters/ft^2).

$$
\left.\begin{array}{ll}
\text{Thin phloem} & \hat{Y} = 4.769 - 0.0146X^3 \\
 & S_{y.x} = 0.21 \\
\text{Thick phloem} & \hat{Y} = 5.006 - 0.0146X^3 \\
 & S_{y.x} = 0.19
\end{array}\right\} r^2 = 0.30;\ P < 0.005
$$

Limits: $0.4 \le x \le 3$

Figure 14.—Female length (mm) as a function of tree diameter (cm) at breast height.

Logan Canyon: $\hat{Y} = 4.357 + 0.049X;\ S_{y.x} = 0.328;\ r^2 = 0.18;\ P < 0.005$

Stillwater: $\hat{Y} = 4.74 + 0.03X;\ S_{y.x} = 0.37;\ r^2 = 0.03;\ P < 0.05$

Figure 19.—Eggs (number) as a function of inch of egg gallery (number).

$$\hat{Y} = 7.65 - \left[A\left(1/2 + 1/2\left[\frac{4.25 - X}{|4.25 - X|}\right]\right) + B\left(1/2 + 1/2\left[\frac{X - 4.25}{|X - 4.25|}\right]\right)\right]$$

$$A = 7.35\ |\ 4.25 - X\ |\frac{2.09}{(3.25)^{2.09}}$$

$$B = 4.50\ |\ X - 4.25\ |\ \frac{1.215}{(9.75)^{1.215}}$$

$1 \le X \le 14$ and $X \neq 4.25$

$S_{y.x} = 2.71;\ r^2 = 0.34;\ P < 0.005$

Figure 21.—Eggs (number) as a function of female length (mm).

A. The average number of eggs laid per inch of gallery.
$\hat{Y} = 2.52 + 0.54X;\ S_{y.x} = 0.91;\ r^2 = 0.09;\ P < 0.05$

B. The average number of eggs laid per day.
$\hat{Y} = -\ 0.261 + 1.06X;\ S_{y.x} = 1.17;\ r^2 = 0.20;\ P < 0.005$

Figure 22.—Eggs (number) as a function of phloem thickness (inch).

A. The average number of eggs laid per inch of gallery.
$\hat{Y} = 4.54 + 9.91X$; $S_{y.x} = 1.3$; $r^2 = 0.16$; $P<0.01$

B. The average number of eggs laid per day.
$\hat{Y} = 3.02 + 9.65X$; $S_{y.x}$ 1.39; $r^2 = 0.14$; $P<0.025$

Figure 23.—Egg gallery (inches) and eggs (number) as functions of temperature (°C).

A. The average number of eggs laid per inch of gallery.
$\hat{Y} = 5.32 - 0.0547(20-X)^{1.48}$; $S_{y.x}$ 1.16; $r^2 = 0.35$; $P<0.005$

B. The average number of eggs laid per day.
$\hat{Y} = 0.146 + 0.06\ (0.75 + 0.01293(X-7)^{2.25})$; $S_{y.x} = 0.91$; $r^2 = 0.70$; $P<0.005$

C. The average length of gallery constructed per day.
$\hat{Y} = 0.014 + 0.986\ (0.274 + 0.00023(X-7)^{3.105})$; $S_{y.x}$ 0.11; $r^2 = 0.81$; $P<0.005$

Figure 27.—Beetles (number) as a function of phloem thickness (inches).

Males and Females: $\hat{Y} = -23.91 + 947.74X$; $r^2 = 0.69$; $S_{y.x} = 27.1$

Females: $\hat{Y} = -13.01 + 587.86X$; $r^2 = 0.65$; $S_{y.x} = 18.5$

Males: $\hat{Y} = -12.74 + 382.52X$; $r^2 = 0.62$; $S_{y.x} = 12.8$

Figure 29.—Beetles (number/ft^2) as a function of egg gallery density (meters/ft^2).

$$\left.\begin{array}{ll} \text{Thin phloem} & \hat{Y} = 111.247 - 7.965(3 - X)^{2.4} \\ & S_{y.x} = 34.5 \\ \text{Thick phloem} & \hat{Y} = 67.262 - 4.816(3 - X)^{2.4} \\ & S_{y.x} = 25.3 \end{array}\right\} r^2 = 0.38;\ P<0.005$$

Limits: $0 \leq X \leq 3$

Figure 30.—Beetles (number/ft of egg gallery) as a function of egg gallery density (meters/ft^2).

Thin phloem $\hat{Y} = 6.157 + 0.3597(3 - X)^{3.5}$
$S_{y.x} = 8.4$

Medium phloem $\hat{Y} = 10.0492 + 0.5870(3 - X)^{3.5}$
$S_{y.x} = 6.6$

Thick phloem $\hat{Y} = 12.755 + 0.745(3 - X)^{3.5}$
$S_{y.x} = 8.6$

Limits $0.4 \leq x \leq 3$

Figure 32.—Lodgepole pine sapwood thickness (inches) as a function of tree diameter at breast height (inches).

$\hat{Y} = -0.471 + 0.2X$

$S_{y.x} = 0.49$; $r^2 = 0.61$; $P<0.005$

Amman, Gene D.; Cole, Walter E. Mountain pine beetle dynamics in lodgepole pine forests. Part II: Population dynamics. Gen. Tech. Rep. INT-145. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 59 p.

This is the second of a three-part series of General Technical Reports concerning the mountain pine beetle in lodgepole pine forests. Part I (Cole and Amman 1980. GTR INT-89, 56 p.) addresses how the beetle "moves through" a lodgepole pine stand, with emphasis on relationships between the beetle and its environmental factors. Hazard rating systems and management alternatives to reduce losses are presented. Part II deals with the taxonomy, biology, and ecology of the beetle. Part III will present methods of sampling mountain pine beetles and modeling efforts.

Part II represents much original research by the authors but is also a review of published literature, primarily on epidemic beetle populations in lodgepole pine forests. Lodgepole pine tree characteristics such as size and phloem thickness have a strong influence on beetle survival, size, sex ratio, and genotype. Of the many mortality factors acting upon the beetle population alone or in combination with other mortality factors, none regulate the population before severe damage occurs to stands of lodgepole pine. These findings offer additional support that the mountain pine beetle is food regulated.

KEYWORDS: Scolytidae, *Dendroctonus ponderosae, Pinus contorta,* population dynamics

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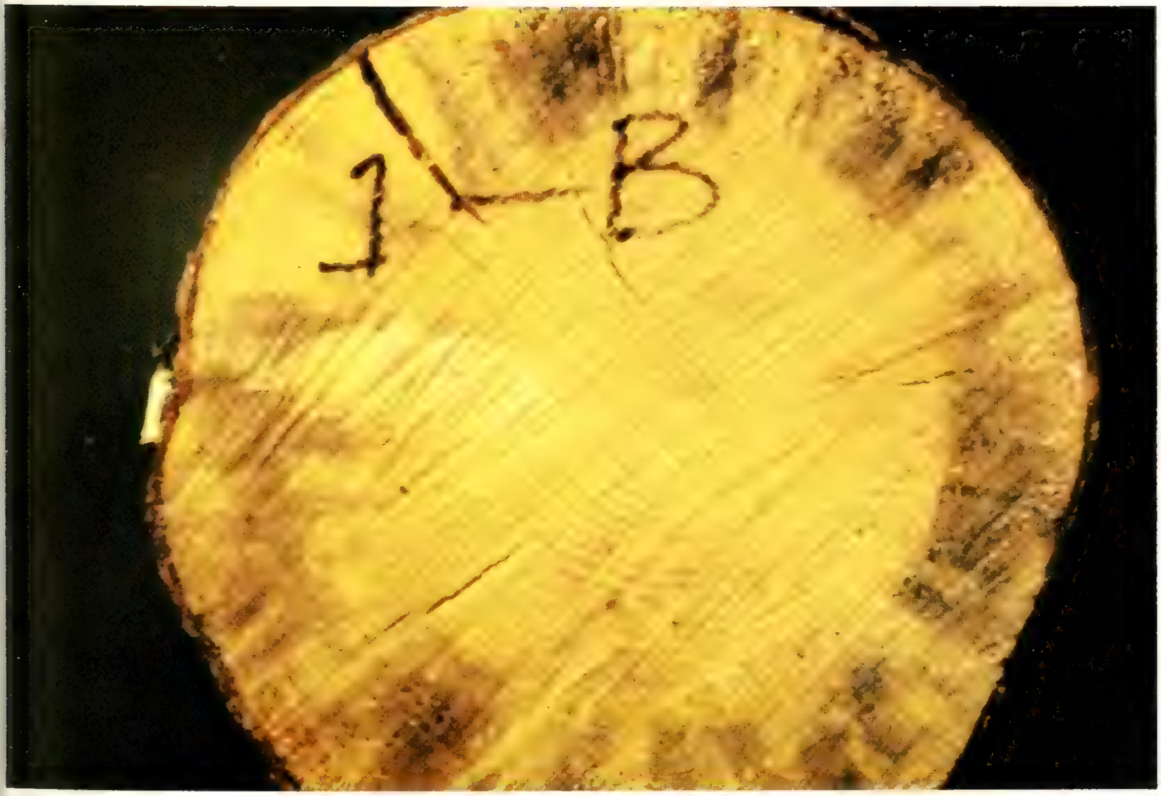
A



B

Figure 33.—Blue-staining fungi, carried into the bark by beetles, discolor the sapwood.
A. Well-developed blue stain fungi usually are uniformly distributed throughout the sapwood.
B. Poorly developed blue stain fungi usually are unevenly distributed in the sapwood. (See p. 00.)

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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**Intermountain
Forest and Range
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Ogden, UT 84401**

General Technical
Report INT-146

June 1983

Blister Rust Resistant Western White Pine for the Inland Empire:

The Story of the First 25 Years of the Research and Development Program

Richard T. Bingham

THE AUTHOR

RICHARD T. BINGHAM, internationally known in the field of forest genetics, retired from the USDA Forest Service in 1974. For 25 years he headed the blister rust resistant western white pine R&D program at the Intermountain Forest and Range Experiment Station's Forestry Sciences Laboratory in Moscow, Idaho. He has authored or coauthored about 25 publications on tree rust resistance genetics. Bingham received his M.S. from the University of Idaho in 1942 in forest pathology. Since retiring, the author, as a Forest Service volunteer, has authored this paper and a guide to Hells Canyon plants. Currently, he is working on a guide to Seven Devils Mountains plants.

RESEARCH SUMMARY

Twenty five years of research and development work (1950-75)—first-phase work undertaken by Forest Service cooperators—has led to experimental production (and soon mass production) of the Inland Empire western white pines bred for blister rust resistance. Breeding has gone through two generations, until 65 percent of the trees resist intense, artificial exposure to the rust fungus. And unless the racial structure of the rust alters disastrously, the long-range survival of these second generation stocks under natural exposure to the rust probably will exceed 65 percent.

Resistance in the second generation stocks is based on selections for general combining ability for a combination of differential and uniform types of resistance. Some of the resistance reactions—and, presumably resistance genes—are identical to those that probably have persisted for long periods near the Asiatic white pine:blister rust gene center. Thus, resistance in these first-phase stocks will probably persist until scientists can produce faster growing and better adapted second-phase stocks embodying more types of resistance genes and more stable resistance.

PROLOGUE

In 1950 four U.S. Department of Agriculture units, which were concerned with the management of western white pine (*Pinus monticola* Dougl.) and control of the white pine blister rust disease (causal pathogen *Cronartium ribicola* J.C. Fisch. ex Rabenh.) in the Inland Empire,[1] began a 25-year program investigating and utilizing genetically controlled resistance to that disease. This research and development venture had a single and practical goal: the rapid and economical development of western white pine planting stock sufficiently resistant and otherwise adapted for Inland Empire planting.

The four USDA units included the Spokane Office of Blister Rust Control (now defunct) of the Bureau of Entomology and Plant Quarantine, and three Forest Service units—the Northern Region, the Northern Rocky Mountain (now part of the Intermountain) Forest and Range Experiment Station, and the California (now Pacific Southwest) Forest and Range Experiment Station. This cooperative work by the four agencies soon became known as the "first-phase resistance program." This implied that any resistant planting stock developed first should satisfy a somewhat limited goal, merely of helping to return western white pine as a manageable component of Inland Empire forests. But also implied in the term "first-phase" was the idea that planting stocks would continue to be improved in subsequent programs toward successively faster growing, better adapted, and more resistant stocks embodying more resistance genes and more stable resistance.

Twenty-five years of R&D work has seen the first-phase program move through two generations of selection for resistance, culminating with the establishment of seed orchards in 1971-74. By about 1985, the 40 acres (16 ha) of seed orchards should be starting to mass produce second-generation (F_2) seed and 65$^+$ percent resistant F_2 planting stock sufficient for annual reforestation of 10,000 to 20,000 acres (4 050 to 8 100 ha) of prime white pine lands.

Objectives of this paper are three:

1. To assemble under one cover the often obscurely published record of research information already available or produced by this and other blister rust resistance research and development programs.
2. To explain how this body of information was interpreted and used in various blister rust resistance programs.
3. To interpret, as objectively as possible, the extent to which success of our first-phase R&D program was influenced by essentially uncontrollable biological conditions, as well as by extraneous administrative conditions that held at the outset or during the progress of this program.

The approach, not altogether in the order indicated above, is to examine the administrative, research, and biological "climates" in force at the inception of our R&D program; then to explain just how much of our success may have been due to timing of the research work, to the state of research knowledge, to forceful execution of the work, and to administrative or biological happenstances.

The format is one hinging about the 1950 beginning of the program. This format emphasizes conditions and factors that influenced success or failure of the program from its start, and that continued to dog its progress through 25 years to its conclusion in 1974.

[1]As used here the Inland Empire is meant to be that geopolitical entity including northern Idaho, northeastern Washington, and northwestern Montana; usually the term is extended to include interior south-central British Columbia

CONTENTS

Blister Rust Resistant Western White Pine for the Inland Empire:

The Story of the First 25 Years of the Research and Development Program

Richard T. Bingham

INTRODUCTION

Some Historical Perspectives

Few forest scientists may aspire to be among those making highly significant contributions to the basic science of plant disease resistance genetics, or even to the art of plant disease resistance breeding. For trees, indeed, make poor materials for basic studies of disease resistance, and research and technology toward developing of disease resistant forest trees will always lag behind the contemporary stage of such work in the annual crop plants. For many years, in fact, tree reproductive and tree disease resistance testing cycles were considered so prohibitively lengthy and costly as to preclude all but a small amount of research. But a substantial and comfortable backlog of basic information on disease resistance has accumulated from the crop plant research (Vavilov 1951). And this legacy has been of great benefit to yesterday's and today's researchers and breeders of disease resistant trees.

State of the Art in 1950

In 1950 it was fair to characterize tree disease resistance genetics and breeding as in its infancy, but as also poised on a threshold of solid research and technology based on work on annual crop plants. Resistance research on three diseases was relatively far advanced because of the epiphytotic nature of the white pine blister rust disease, the chestnut blight (pathogen *Endothia parasitica* [Murr.] P. & H. Anders.), and the Dutch elm vascular disease (*Ceratocystis ulmi* [Buism.] C. Moreau) where introduced among susceptible host populations in Europe and North America.

It is enlightening to look back at early tree disease resistance research and to assess its utility in terms of today's tree breeding programs. Experimentation had begun in the 1910's, but by 1950, aside from a few mostly vegetatively propagated and often horticultural varieties, the widespread use of disease resistant forest trees was almost nil. Nevertheless, a few significant contributions had begun to accumulate. These indicated the progress and promise of tree disease resistance and breeding work in general as follows:

1. Zederbauer (1912) conducted what for the time were quite sophisticated experiments into the development of wind-pollinated, individual-tree progenies of eastern Austrian, western Czechoslovakian, Norwegian, Finnish, and Scottish provenances of Scotch pine (*Pinus sylvestris* L.). These experiments clearly demonstrated intraspecific, less clearly interracial variations in percent of seedlings killed by the endemic needle cast disease caused by *Lophodermium pinastri* (Fr.) Chev. Mortality ranged between 4 and 64 percent in progenies from 12 eastern Austrian and 1 southwestern Czechoslovakian trees, while none of the seedlings from 9 other eastern Austrian and 3 Norwegian, Scottish, or Finnish trees were killed.

2. Van Fleet (1914, 1920) and later Graves (1925) isolated interspecies variations in resistance to the chestnut blight disease caused by *E. parasitica*. The Asiatic chestnuts *Castanea mollissima* Bl. and *C. crenata* Sieb. + Zucc. proved to be quite resistant in respect to the susceptible American chestnut *C. dentata* (Marsh.) Borkh. This work led to many years of interspecies hybridization work, seeking to transfer resistance from the Asiatic chestnuts to the better timber type American chestnut.

3. Moir (1920, 1924) and Spaulding (1922, 1923, 1925, 1929) assembled a massive body of widespread and detailed observations on the relative susceptibility to blister rust of some 16 Eurasian and North American white pines. A very clear picture emerged of the generally greater resistance of the Eurasian species. Interspecies hybridization work, in part seeking to transfer resistance of the Eurasian to the North American white pines, got under way in the late 1930's (Duffield and Stockwell 1949; Johnson 1939a; Righter 1945). About the same time Snell (1931), Riker and Kouba (1940a, 1940b), and Johnson and Heimburger (cf. Farrar 1947) commenced investigating intraspecies variations within *Pinus strobus* L. Before long Riker and others (1943a, 1943b) and Johnson and Heimburger (cf. Farrar 1947) had established that intraspecies variation in blister rust resistance was, in fact, under genetic control, although there were conflicting results as to the degree of its inheritance in wind-pollinated progenies from presumably resistant parental selections.

4. Liese (1930a, 1930b), in experiments with various provenances of *P. sylvestris*, demonstrated interracial variations in resistance to the disease caused by the endemic and autoecious rust *Peridermium pini* (Pers.) Lev. Later, in what for the times were elegant and classic experiments using *P. sylvestris* progenies produced by controlled pollination, Liese (1936) demonstrated that intraspecific variation in resistance to the rust probably also existed within *P. sylvestris*. Small (10- to 23-tree) progenies from the crosses S (susceptible mother tree) × S, S × R (resistant mother tree), R × S, and R × R were found to contain resistant offspring in the ratio 31:52:82:83 respectively.

5. Buisman (1935), sought to replace certain widely used Netherlands elm clones that had proved to be universally susceptible to the introduced Dutch elm disease caused by *C. ulmi*. She demonstrated and isolated intervarietal and interspecific variation in resistance to that disease. This laid the groundwork for today's fruitful Dutch elm disease resistance programs.

From 1920 to 1950 three review articles were published that considered the attainments and promises in the field of breeding disease resistant trees (Hartley 1927; Graves 1948; Clapper and Miller 1949). While these reviews offered a good deal of encouragement as to the likelihood for making genetic gains in forest tree disease resistance, they presented almost no specific data bearing on the genetics and inheritance of resistance. Hartley's (1927) article, however, deserves special mention. His suggestions as to how breeders might use intraspecies variation in resistance to blister rust in *P. strobus* were so perceptive and far ahead of the times as to be almost prophetic (see section on "The Intraspecies Approach").

White Pine Blister Rust Resistance in 1950

Probably the state of the art of breeding for blister rust resistance in white pines in 1950 can best be characterized as "in a state of readiness."

The pathogen *C. ribicola* was quite well understood. We were conversant with its biology and etiology (Klebahn 1905; Colley 1918; Clinton and McCormick 1919). We were particularly aware of the disease's awesome epiphytology as it had been introduced into and spread within planted stands of *P. strobus* in Europe (von Tubeuf 1905–1936; Moir 1920; Spaulding 1922), as well as into native northeastern North American stands of *P. strobus* (Snell 1928; Hirt 1936) and northwestern North American stands of *P. monticola* (Mielke 1943; Buchanan 1938; Buckland 1946) and *Pinus lambertiana* Dougl. (sugar pine) (Mielke 1938).

The technology for resistance testing was largely in hand. Successful methods for inoculating white pine test materials with *C. ribicola* had become available even before 1920 (Spaulding 1912; Clinton and McCormick 1919) and constantly had been improved thereafter (York and Snell 1922; Snell and Rathbun-Gravatt 1925; Hirt 1939; Van Vloten 1939; Riker and others 1943a, 1943b; Slipp 1949). And Cumming and Righter (1948) had just completed an impressive job of improving techniques for controlling pollination in *Pinus*. This meant that reliable methods were available for producing either interspecific or intraspecific hybrid test progenies of guaranteed pedigree.

Two probable sources of genetically controlled resistance to the white pine blister rust disease had been ascertained. There was strong evidence that the several Eurasian white pine species constituted a repository of resistance (Spaulding 1929; Hirt 1940; Childs and Bedwell 1948). And there were persistent reports that rare but presumably resistant individuals were surviving in otherwise severely rust-damaged stands of the susceptible North American white pines (Snell 1931; Schreiner 1938; Riker and Kouba 1940a, 1940b; Farrar 1947; Hirt 1948 in *P. strobus*; Lachmund 1934; Mielke 1943 and Buckland 1946 in *P. monticola*; Mielke 1943 and Childs and Bedwell 1948 in *P. lambertiana*).

Thus, for workers seeking to improve resistance in these commercially important North American white pines, there was a question as to whether it was more efficacious: (1) to introduce the possibly more broadly based and stable resistance from Eurasian white pines that had long been associated with the rust, plus any adaptational problems, via interspecies hybridization; or (2) to seek and utilize intraspecific variations for resistance that appeared to be available in the locally well-adapted, rust-free survivors residual in long and heavily infected stands of native white pines.

Almost nothing was known, except inferentially, about the genetic control of white pine blister rust resistance, and little more was known about the degree of inheritance of resistance as it might pertain to the practical and economical production of resistant planting stocks. In fact, the weightiest evidence obtained in the more critical early studies in Wisconsin and Canada (Riker and others 1943a, 1943b; and Farrar 1947) was contradictory and open to differing interpretations (see section on "The Intraspecies Approach").

Thus, resistance research in the white pines:*C. ribicola* couplet, as that in the *Castanea:E. parasitica* and *Ulmus:C. ulmi* couplets, was poised on a threshold of research and technology from studies on disease resistance in annual crops as well as in trees. All required was a gentle nudge to cause it to fall ahead.

Administrative, Research, and Biological Climates in 1950

The administrative climate in the four cooperating USDA agencies of the late 1940's and early 1950's certainly was favorable. Control of the white pine blister rust disease in the commercial and highly valuable western white pine stands of the Inland Empire had by then become the primary concern of local disease control and forest management personnel (Davis and Moss 1940; Davis 1942; Matthews and Hutchison 1948).

The rust disease had entered several northern Idaho *P. monticola* stands in 1923, but remained undetected there until 1927 (Mielke 1943). Even before the rust was discovered in Idaho, experimental work started toward adapting and improving techniques for eradication of the heteroecious blister rust's alternate hosts (*Ribes* spp., hopefully eradicated to the extent that their populations would be nearly eliminated in and near white pine stands).

By the early 1940's, it was becoming apparent that *Ribes* spp. eradication to a large extent was controlling spread of the rust in *P. strobus* stands of the Northeastern and Lake States, but that it might be far less effective in controlling rust spread between and within Inland Empire *P. monticola* stands (see Ketcham and others 1968 for reasons). In 1937, only 15 years after the rust's entry into Idaho, blister rust disease surveys showed that the average level of infection on young *P. monticola* trees over the entire St. Joe National Forest already had reached 15 percent (Swanson 1939). By the mid-1940's in certain high-rust-hazard areas, infection had climbed to over 95 percent, prospective damage to dominant and codominant white pine poles (crop trees) to over 70 percent—all in less than 20 years (Bingham 1947). As foresters would say, white pine blister rust epiphytotics in Inland Empire western white pine stands were, bar none, the world's most spectacular.

Thus, by 1950, the long and often discouraging blister rust control battle in the Inland Empire was almost 25 years old. Most key control personnel had been on the job, except as interrupted by World War II, for 15 to 25 years. Those administrators tenacious enough to stay with the fight were a strongly motivated, highly experienced, and close-knit group with exceptional morale. They learned the hard way to be adaptable and receptive to the implementation of newer and possibly better means of control.

The research climate of the early 1950's was almost, if not quite, as favorable. Not until the mid-1950's and early 1960's did the forestry research funds and work force begin to multiply. Research funds had lagged about 5 years behind compared to the postwar buildup in rust control. Thus, in 1950, ample blister rust control funds were available for undertaking developmental work on resistance, but research funds were not. However, since there was the usual grey area as to what constituted development and what research, there was scant criticism when financially adroit control administrators saw fit to subsidize some of the preliminary research.

Perhaps most important, by 1950 the materials for researching blister rust resistance (here rust-free parent selections gleaned from rust-decimated *P. monticola* stands) had, biologically, reached a particularly advantageous stage in their development. Our unpublished data reveal that at that time our blister rust epiphytotics could be characterized by susceptible:healthy tree ratios of from more than 375 dead and dying crop trees:1 surviving crop tree, or even up to 10,000 ± infected trees:1 completely rust-free tree. Obviously, under these conditions strong selection pressures had been exerted on the existing generation of white pines by the rampant rust disease. Remarkably rust-free trees remained, and after more than 25 years of annual assault by the rust, it was difficult to accept the hypothesis that they were merely "escapes." Conversely, it was easy to accept the hypothesis that the strong selection pressure exerted by the rust had exposed most of the susceptible individuals, or to assume that healthy survivors of the epiphytotics were indeed genetically resistant.

Thus, the early 1950's seemed almost ideal for starting a program of researching and using heritable blister rust resistance in Inland Empire *P. monticola*. The overall climate hardly could have been better—administratively, financially, or biologically. All that was needed for success was a moderately competent research and development team. If team members had the ability to adapt existing research findings and technology to their needs, and if they had a little more biological good luck, success would be theirs.

REVIEW OF THE PRE-1950 LITERATURE

The Interspecies Approach

Seeking to transfer inherent resistance from Eurasian white pine species.—The useful concept of "gene centers" was not available in 1950 (see Leppik [1970] on the gene center of the white pines:*C. ribicola* couplet). Nevertheless, much evidence had accumulated on the existence of geographic areas with repositories of tree disease resistance: in the *Castanea:E.* parasitica couplet (Gravatt and Gill 1930; Gravatt 1949; Graves 1950); the *Ulmus:C. ulmi*:couplet (Buisman 1935); and the white pines:*C. ribicola* couplet. A question remained as to whether there was a single Asiatic center from which *C. ribicola* had spread to Europe and America (Spaulding 1929; Leppik 1970), or if there were two such centers, one in Asia and one in the European Alps (Gäumann 1948).

Very early Tranzschel (1895) had noted the differential susceptibility (or resistance) of the Asiatic white pine *Pinus sibirica* DuTour and the European white pine *Pinus cembra* L. Tubeuf's observations (1917, 1920, 1926, 1933) then further clarified the situation in the white pines:*C. ribicola* couplet by emphasizing the high susceptibility of most North American white pines (particularly *P. strobus*) when compared with Eurasian white pines. Pennington and others (1921) extended these findings on the relatively high susceptibility of the North American white pines (*P. strobus* and *Pinus flexilis* James) in relation to the European *P. cembra* in small Rhode Island plantings.

Later Moir (1920 and 1924) and Spaulding (1922, 1923, 1925), as official U.S. Department of Agriculture observers reviewing the status of white pine blister rust disease in Europe, brought back hundreds of detailed observations on the relative susceptibility of seven Eurasian white pines and nine North American white pines where widely planted in western Europe and Scandinavia. Their keen and widespread European and North American observations on the blister rust epiphytotics then developing in *P. strobus* and *P. monticola* stands, led to Spaulding's preliminary (1925) and final (1929) classifications of the relative blister rust resistance of some 16 of the world's 20-odd white pine species. Spaulding (1925) attributed part of the resistance of the Eurasian white pines to the relatively short number of years they retained their needles, and possibly also because their stomata tended to be restricted only to the outer surfaces of the needles.

These early observations pointed out the need for clearer delineation and quantification of this interspecies variation in resistance. Ultimately they led to the establishment of more sensitive tests made under North American conditions including one within the range of *P. strobus* in central New York (Hirt 1940), the other within the range of *P. monticola* in southern British Columbia and near Mt. Hood in northwestern Oregon (Childs and Bedwell 1948). In table 1, salient results of these two tests are tabulated and compared with Spaulding's (1929) observations.

The practical implications of these findings slowly became apparent. The immediate prospect was that piecemeal introduction of resistant Eurasian species might fill some of the gaps left by European or North American blister rust epiphytotics. However, on closer inspection, it soon appeared that silvicultural limitations (slow growth, procumbent habit, rapidly tapering bole form, coarse branching, and cold sensitivity) would preclude introduction of most Eurasian species and provenances for other than experimental purposes.

More troublesome, it also became apparent that it was difficult, if not impossible, to secure any reasonably useful amounts of seed of the faster growing, better formed, and cold-hardy provenances of the more promising resistant species *P. peuce, P. griffithii, P. armandii*, and *P. koraiensis*. This was because these species remained little known and quite inaccessible (see p. 97–271 in Bingham and others [1972] for detailed information on the distribution and intrinsic qualities of the world's white pine species). Any direct and extensive introduction of resistant Eurasian white pine thus never really got under way.

A second prospect (and the main subject of this section) was that the resistance of the Eurasian white pine might be transferred to the very susceptible but nearly ideal timber type, North American white pines (*P. strobus, P. monticola* and *P.*

Table 1.—Review of pre-1950 investigations into the relative blister rust resistance of various white pine species

Taxonomic section subsection species[1]	Common name	Main distribution	Spaulding (1929)		Hirt (1940)		Childs and Bedwell (1948	
			General classification	Rank[3]	Numerical classification	Rank[3,5,6]	Classifications General	Numerical[7]
STROBUS								
STROBI								
Pinus armandii Franchet	Armand pine	Central and South-western China	Immune	1[4]			Resistant	1.0
Pinus griffithii McClelland	Blue pine	Northern Pakistan and India, Nepal and Bhutan	Resistant	3			Resistant	2.0
Pinus peuce Grisebach	Balkan pine	Yugoslovia, Albania, and Bulgaria	Resistant	4	0.39	4	Moderately susceptible	1.7
Pinus parviflora Sieb. & Zucc.	Japanese white pine	Japan	Resistant	8[4]				
Pinus strobus Linnaeus	Eastern white pine	Eastern United States and Canada	Susceptible	10	.71	6	Susceptible	3.6
Pinus ayacahuite Ehrenberg	Mexican white pine	Southern Mexico	Susceptible	11[4]				
Pinus lambertiana Douglas	Sugar pine	Southern Oregon and North-central California	Susceptible	12[4]			Exceedingly susceptible	6.2
Pinus strobiformis Engelmann	Southwestern white pine	Southwestern United States and Northern Mexico	Susceptible	13[4]	.69	5	Susceptible	3.0
Pinus flexilis James	Limber pine	Southwestern Canada and Central Northwestern Interior United States	Very susceptible	15	1.01	7	Susceptible	3.8
Pinus monticola Douglas	Western white pine	Southwestern Canada and Northwestern United States	Very susceptible	16	1.16	8	Very susceptible	4.7
CEMBRAE								
Pinus cembra Linnaeus	European stone pine	European Alps	Resistant	2	.00	1	—	—
Pinus koraiensis Sieb. & Zucc.	Korean pine	North Korea and Eastern China	Resistant	7[4]	.11	3	Resistant	2.0
Pinus sibirica DuTour	Siberian stone pine	Siberia and Northern Mongolia	Susceptible	9			—	—
Pinus albicaulis Engelmann	Whitebark pine	Southwestern Canada and Interior Northwestern United States	Very susceptible	14			Most susceptible	—
PARRYA								
BALFOURIANAE								
Pinus aristata Engelmann[2]	Bristlecone pine	Interior West-Central United States	Resistant	5[4]	.03	2	Moderately susceptible	1.3
Pinus balfouriana Grev & Balf	Foxtail pine	Central and Northern California	Resistant	6[4]				—

[1]Taxonomy follows Little and Critchfield (1969).
[2]Recently P. aristata has been separated into two species (Bailey 1970).
[3]Rankings are in order of increasing susceptibility.
[4]Spaulding's (1929) rankings were based upon observations of small numbers of trees.
[5]Hirt's (1940) numerical classification was based on $\sqrt{\text{no. cankers/M}}$ needles inoculated, expressed as the number of cankers greater (+) or lesser(-) than foun *strobus* (in other words, *P. strobus* = 0.00). Here, Hirt's $\sqrt{\text{no. cankers}}$ are rearranged to show their variation between the most resistant species (*P. cembra* = 0. the most susceptible species (*P. monticola* = 1.16) tested.
[6]The rankings are the author's, but they follow Hirt's (1940) numerical rankings.
[7]Childs and Bedwell's (1948) numerical ranking was based on number of cankers produced from one million needles exposed to *C. ribicola* for one season. H author has averaged these numbers from Childs and Bedwell's table 1, across one to seven different tests.
[8]*Pinus albicaulis* was not included in Childs and Bedwell's (1948) main field tests, probably because it became so severely infected in the nurseries transplanting to the field test plots. However, in two other studies (Bedwell and Childs 1943), it supported so many more cankers than *P. monticola* (6.4 to 20 more cankers) that they ranked it as even more susceptible than *P. lambertiana*.
[9]*Pinus balfouriana* had such low nursery survival that it was not entered in Childs and Bedwell's (1948) main field tests. However, they found it "often infec an arboretum near Carson, Wash.

lambertiana), via interspecies hybridization. This prospect was especially attractive for a number of reasons:

1. Biologically, such hybrids indeed were feasible. At least three different spontaneous hybrids involving the better Eurasian and the North American white pine species (from within subsection Strobi) already had been reported as occurring naturally in European or North American arboreta and gardens (one each by Jackson 1933, Rehder 1940, Sax 1947).

2. Remarkable success already had been achieved in transferring disease resistance by interspecies and intervarietal hybridization in annual crop plants (tobacco, cotton, potatoes, and others), and then by restoring quality and yield through repeated backcrossing to the commercial variety (Thomas 1952). Promising early results already had been obtained in transferring chestnut blight resistance from the resistant Asiatic chestnuts *C. mollissima* and *C. crenata* to the better timber type but highly susceptible American chestnut *C. dentata* (Clapper and Gravatt 1936; Graves 1940).

3. Certain hybrids, notably in maize after outcrossing of repeatedly inbred lines (see Jones 1920 and East 1936), were exhibiting a strikingly increased yield, and this "hybrid vigor" seemed to hold, at least for the juvenile *P. strobus* × *P. monticola* F_1 hybrid (Righter 1945; Buchholz 1945; Stockwell and Righter 1949).

As a result, a flurry of new work began in the production and testing of white pine species hybrids. At first reports concerned mainly the biological feasibility, production technology, and potential hybrid vigor of the F_1 hybrids (Duffield and Stockwell 1949; Righter 1946; Johnson and Heimburger 1946; Righter and Duffield 1951). Soon Righter (1946) outlined the possibilities and economics of mass production of pine hybrids. Through 1950, Righter and Duffield (1951) had reported successful, artificial production of 10 different white pine hybrids, eight of them involving resistant Eurasian white pines.

From this early work in interspecies hybridization, it emerged that: (1) crosses between resistant Eurasian species and susceptible but commercially important North American species within taxonomic subsection Strobi were mostly successful, except those involving *P. armandii* or *P. lambertiana*, which mostly were unsuccessful or difficult; and (2) intersubsectional crosses involving resistant Eurasian stone pines of subsection Cembrae and the susceptible North American species of subsection Strobi were mostly unsuccessful or difficult (see table 1 for taxonomic subsections of white pine species).

Results of nursery or field tests of these hybrids to determine their blister rust resistance, or their long-range adaptation and growth, were still awaited in 1950.

The Interracial Approach

Seeking to use any provenance-related resistance in *P. strobus*.—In retrospect, it is curious that in European experiments of the late 1930's a definite attempt was made to isolate interracial variations for blister rust resistance among *P. strobus* provenances. Although today we might predict only a low, probably chance possibility for the existence of such racial variation, in the light of the times its existence would have seemed quite reasonable. The literature of the period, in fact, was liberally sprinkled with reports of racial variations in tree disease resistance—in the *Pinus sylvestris:Peridermium pini* couplet (Liese 1930a, 1930b), the *Pseudotsuga menziesii* (Mirb.) Franco:*Rhabdocline pseudotsuga* Syd. couplet (Rohde 1934), and others.

This search for interracial resistance may have started from a suggestion of Liese (1936). Based on his finding of provenance-related resistance in the endemic and more or less balanced *Pinus sylvestris:Peridermium pini* couplet (Liese 1930a, 1930b), he suggested the extension of that finding to the epiphytotic and unbalanced *P. strobus:C. ribicola* couplet.[2] Liese's (1936) suggestion came from Liro's (1907) assumption that the existence of racial variation for blister rust resistance in *P. strobus* long since had been demonstrated by Eriksson (1896) and by Tranzschel (1895).

Eriksson's (1896) evidence, however, really was flimsy. He observed what he considered to be wide variation in susceptibility to blister rust in two nursery beds that contained 7- to 8-year-old *P. strobus* plants each from a different seed source. However, one bed contained only 10 plants. And Tranzschel (1895) actually observed what he considered to be varietal, not interracial, resistance to blister rust demonstrated in adjacent seedbeds of the then-defined Siberian and Alpen varieties of *Pinus cembra*. Today these varieties are considered quite discrete and geographically well-separated species, *Pinus sibirica* and *P. cembra* (Little and Critchfield 1969).

Van Vloten (1939, 1941) instituted a fairly large Dutch experiment, exposing seedlings from various provenances of *P. strobus* to *C. ribicola* spreading from interplanted *Ribes nigrum* L. bushes. Initially Van Vloten (1941) noted rather uniformly heavy infection in all provenances as disclosed by typical needle and bark lesions, but also that formation of aecia varied widely (between 0 and 72 percent). Later Van Vloten (personal communication of Feb. 14, 1956) reported that 98 to 100 percent of the plants in all provenances had become infected and that most of them died on transplanting.

This sort of research was also under consideration in Germany. Heimburger (1956) reported that in 1937 he had been engaged in collecting *P. strobus* seed for proposed German experiments on racial variations in blister rust resistance.

The Intraspecies Approach

Seeking to use any resistance available in rare rust-free selections of North American white pines.—As far as can be determined, Dr. Carl Hartley (1927) of the U.S. Department of Agriculture, Bureau of Plant Industry, Division of Forest Pathology, was the first scientist to advocate intraspecies breeding (within the species *P. strobus*) to isolate and utilize genetic resistance to the white pine blister rust disease. Hartley apparently based some far-reaching recommendations on resistance breeding on the performance of a single *P. strobus* tree that Dr. John Shaw Boyce at the Yale University School of Forestry had observed to be tolerating attack by *C. ribicola*. Nevertheless, Hartley's prediction on the latent nature of resistance in North American white pine, and his several suggestions as to how researchers might explore and use intraspecific variation in *P. strobus*, were so remarkable for the time that they are worth repeating in more modern terminology:

1. Given time, natural selection favoring resistance would uncover latent resistance first in *P. strobus*, later in *P. monticola*, by directing attention to those individuals that survived the ongoing blister rust epiphytotics. Also, the general level of resistance in *P. strobus* probably would be higher than that so far found in *Castanea dentata* to the chestnut blight.

[2]This and all subsequent footnote material found in the text (not on tables) is anecdotal. Thus, these footnotes are removed from the text to the appendix.

2. "Line selection" for resistance could be started immediately in *P. strobus*. This artificial selection would be applied merely through collections of wind-pollinated seed from the widely dispersed survivors that might be found early in the wake of still-advancing blister rust epiphytotics.

3. In the future, "crude mass selection" would be applied by the rust itself, in time leaving small, yet intercrossing populations of surviving, resistant *P. strobus* trees, from which such mass-selected seed might be collected.

4. One "less empirical procedure" for resistance breeding should be followed. This involved checking the resistance of a number of epiphytotic-surviving and presumably resistant parent selections by exposing 50 or more of their vegetative propagules (grafts), alongside ordinary nursery or control seedlings, for 10 to 15 years in a disease garden with planted *Ribes* spp. bushes. Finally, the disease garden would be converted into a clonal seed orchard by culling the susceptible clones and controls.

5. Another "less empirical procedure" would be to establish the disease garden with offspring from controlled crosses among the presumably resistant parent selections. This would determine which parents transmitted the highest levels of resistance to their seedling progenies. The researcher could then establish clonal seed orchards with grafts taken from those parental selections that transmitted the highest levels of resistance. This procedure was apparently the suggestion of Hartley's colleague, Dr. Wilber Brotherton, Jr., a crop plant disease specialist also with the Bureau of Plant Industry.

The events that followed showed just how perceptive were Hartley's (1927) predictions as to the latency and nature of blister rust resistance in North American white pines, and just how farsighted were his suggestions as to profitable breeding methods. In fact, each of his suggestions is in use today in one or another of the present programs for blister rust resistance breeding.

Thus, quite soon and precisely in line with Hartley's (1927) prediction, remarkably blister-rust-free and probably resistant survivors began to appear, with increasing frequency, in the progressively more and more heavily rusted stands of North American white pines. They appeared first in *P. strobus* stands (Snell 1931; Schreiner 1938; Riker and Kouba 1940a, 1940b; Farrar 1947; Hirt 1948), later in similar *P. monticola* stands (Lachmund 1934; Mielke 1943; Buckland 1946) and *P. lambertiana* stands (Mielke 1943; Childs and Bedwell 1948).

Next, using Hartley's (1927) suggestion on "line selection," Snell (1931) tested exposure of wind-pollinated progeny from a single, presumably resistant New Hampshire *P. strobus* selection to heavy, natural inoculation with *C. ribicola*. The result, in Snell's words as later quoted by Mirov (1938), was: "The trees from the resistant pine were not more resistant than trees from normal seed." Snell qualified this by remarking, "Of course, it must be held in mind that no one has any information regarding the staminate parent in the production of these seeds, but it is extremely likely that the pollen entering into combination came from susceptible parents for the most part." Later Snell (personal communication of March 30, 1973) noted that by 1934—5 years after first rust exposure—the seedlings from the New Hampshire selection were 58 percent infected, while control seedlings were 48 percent infected.

Before long a much larger and more conclusive test of this "line selection," as well as of Hartley's (1927) suggestion for confirming resistance of parental selections via their vegetative propagules, was being set up in the Lake States. These new tests were part of a pioneering, blister rust resistance R&D program led by the University of Wisconsin (Dr. A. J. Riker, plant pathologist), in cooperation with the USDA Bureau of Entomology & Plant Quarantine (T. F. Kouba and L. E. Byam, blister rust control officers), and the Wisconsin Conservation Department (W. H. Brener, nurseryman).

First, working in natural, Wisconsin *P. strobus* stands they considered to be heavily blister rusted, the cooperators selected individual, rust free white pines and collected scionwood and wind-pollinated seed therefrom (Riker and Kouba, 1940a, 1940b). Next, they grafted scions from the resistant parental selections on ordinary *P. strobus* rootstocks, pruned away rust susceptible rootstock foliage, and exposed the grafts along with wind-pollinated seedlings of the same selections to natural and artificial blister rust inoculation in a blister rust disease garden near Wisconsin Rapids, Wisc. Soon (as did Snell, via Mirov, 1938 and via Bingham, personal communication) the Wisconsin cooperators were reporting discouraging results in respect to the transmission of resistance to wind-pollinated offspring of rust free selections. At the same time, however, they reported that grafts from most of the same selections appeared to be resistant (Riker and others, 1943a, 1943b).

The initial test (Riker and others 1943a, 1943b) included wind-pollinated progenies from 63 Wisconsin *P. strobus* selections, exposed in the disease garden in two naturally inoculated and two naturally and artificially inoculated replicates. Each replicate included both wind-pollinated progenies and grafts from the same "resistant" parent selections, plus ordinary and presumably susceptible *P. strobus* control seedlings. In the case of the wind-pollinated seedlings from selections, results showed that an average of 78 percent of 384 control seedlings, versus 75 percent of the 1,494 seedlings from resistant selections, supported blister rust stem cankers only 12 months after inoculation. These results came from averaging the percentages of infections for the two artificially inoculated replicates.

In identical test replicates the Wisconsin researchers produced some encouraging results on performance of vegetative propagules from the same 63 *P. strobus* selections. By averaging their results from the two artificially inoculated replicates (as done above) it appeared that only 9 percent of 156 grafts from resistant selections were stem cankered 12 months after inoculation. Also, there were outward and visible evidences of genetically controlled resistance and resistance mechanisms on grafts (Riker and others 1943b, 1949, 1953). These included small size of foliar lesions (under $1/2 \times 1$ mm), apparent failure of rust mycelium to extend from infected needles into the branch or stem bark, bark lesions that were reduced both in number and size, bark lesions that were "corked out" and with rust fungus therein presumably dead, relatively slow extension of bark lesions (in branches, to the extent that the fungus failed to reach the stem only a few inches away before the branch died), and failure of branch and stem lesions to produce aecia.

Based on these preliminary results, Riker and others (1943a, 1943b, 1949) drew the following inferences:

1. Continued survival of parental selections, overall high resistance of their grafts, and the outward signs of resistance and resistance mechanisms thereon all indicate genetic control of blister rust resistance in *P. strobus*.

2. Overall low resistance of wind-pollinated progenies from parental selections indicate that any resistance the offspring had inherited was being masked, either by (a) dominant susceptibility-gene(s) of the unknown but probably predominantly susceptible pollen parents, or (b) the overwhelming severity of the natural and artificial inoculations of the tests.

3. Emphasis should be placed on vegetative propagation and toward reproducing those parental selections whose grafts resist infection (an inference already drawn from Snell's data by Mirov [1938]).

Exercising traditional "good hindsight," it seems all three of these inferences should have been drawn only with certain reservations. The first was questionable because "graft-controls" (grafts from ordinary susceptible trees, preferably of the same ages and localities as the resistant selections) were not included in the tests; therefore, any physiological effects of graftage on resistance could not be appraised. Much later Patton and Riker (1958b) and Patton (1961) showed the pronounced effect of parent tree age on apparent resistance of grafts.

The second inference also was open to question because: (1) lack of control of pollination perhaps should have precluded the making of any working assumptions as to the gene-control that was being exercised in the inheritance of resistance, and (2) if there existed some lower "field level" of resistance, then why was this threshold resistance not overcome in the grafts as well as in the wind-pollinated seedlings?

The third inference as to the desirability of emphasizing work on vegetative propagations of *P. strobus* also was open to question. It assumes that the first two somewhat shaky inferences were acceptable. It also apparently was based on what might prove to be overly optimistic predictions on significant seed production on young grafts and on the acceptance of somewhat shaky financial risks.

For instance, it was predicted that grafts from 30-year-old resistant selections could be planted where mostly isolated from outside pollination and induced to produce cones and seed (at least adequate for further testing) within as little as 4 to 5 years. This time frame seems unduly optimistic for white pines even in view of promising results then commonly being reported for other conifers (Lindquist 1948; Syrach Larsen 1956). The shaky financial risk lay in the possibly low resistance level that might result in the "control-pollinated" progenies obtained by wind pollination within the isolated graft planting. Testing for resistance (say over 10 years—5 years for graft seed production and 5 years for resistance testing) might prove that inherent levels of resistance were too low for practical planting use. If so, then any use of the experimental graft planting as a seed orchard might have to be abandoned, and the planting perhaps used only for further testing with the polycrossed "control-pollinated" progenies.

In any event, these early inferences or preliminary conclusions of Riker and others (1943a, 1943b) persisted in the literature for more than 10 years. They trickled into the review literature (Graves 1948; Clapper and Miller 1949), and may have delayed not only the Wisconsin but other programs (Buckland 1946) for developing blister rust resistant planting stocks. Seven years later Riker and others (in a paper presented in Stockholm in 1950, but delayed in publication until 1953) first reported that wind-pollinated seedlings in progenies from certain "most resistant" parental *P. strobus* selections indeed had survived the heavy inoculation of their tests in "significantly better" proportions than had control seedlings. Just how much "better" had been survival in these particular, open-pollinated progenies was not specified.

In the Wisconsin program, perhaps unfortunately, a good deal of emphasis was shifted to research into vegetative propagation of *P. strobus* and to the establishment of graft outplantings throughout northern Wisconsin (Patten and Riker 1966). Cuttings taken from older trees, such as the 25- to 40-year-old Wisconsin selections, rooted only from 1 to 20 percent in extensive trials (Thomas and Riker 1950). Thus, the technology for economical mass-production of vegetative propagules of older *P. strobus* selections simply defied development.

Meanwhile, Canadian workers, apparently from experiments planned and installed about the same time as the Wisconsin experiments, were coming up with quite different and much less clear results. According to Farrar (1947), Johnson and Heimburger's tests, made under the auspices of the Canadian National Research Council and the Dominion Forest Service, included some "40 different strains." Presumably these included wind-pollinated stand collections and wind-pollinated progenies from individual "resistant" *P. strobus* selections. The tests were made mainly in a Montreal disease garden and included unidentified University of Wisconsin and Harvard University strains, along with wind-pollinated progenies coming from noteworthy survivors found in a rust-decimated, Pointe Platon, Quebec, plantation. Farrar (1947) reported that after 8 years of exposure to natural inoculation by *C. ribicola* in the disease garden, certain unidentified strains of *P. strobus* became almost 100 percent infected while others remained almost free of the rust. Unfortunately, the Canadian program was interrupted when researchers transferred to other work and other stations; in fact, Heimburger (1956) was later unable to find, reassemble, and reassess the original data.

A pertinent question remains about the contradictory nature of the early Wisconsin and Canadian results. Why was it that Brotherton's suggestion (Hartley 1927) concerning the probable utility of control-pollinated test progenies was never pursued? Today it seems obvious that by controlling pollination, the researchers would produce much sounder evidence concerning the nature and inheritance of any resistance-genes; also, that findings would become available in one short (say 5- to 7-year) pollination and resistance test cycle. They would also answer important questions about the level of resistance to be obtained in the first breeding generations and about whether that level was adequate for using such "early generation" stocks for practical reforestation.

One answer might be that foresters and forest pathologists of the time (the author included) had only sketchy training in genetics, or even hesitated to extend to trees the successful research and technology from agronomic work. Or perhaps the researchers had not been exposed to the new technology for controlling pollination in pines. This technology, although dating at least from the early 1930's (Liese [1936] had reported the use of cloth bags to control pollination in *P. sylvestris*), had not been refined and made generally available until the late 1940's (Cumming and Righter 1948).

In respect to physiologic or pathogenic races of *C. ribicola*, almost nothing was known through 1950. Hahn (1949a, 1949b) had discussed the continuing immunity of certain red and black

currant varieties. He suggested that as long as existing and new races (if any) all gave the same reaction on these varieties, then, new races capable of attacking the immune currants probably had not appeared. Riker and others (1943b) and Boyce (1948) merely mentioned that there were then no evidences for *C. ribicola* races.

Summary of Past Research

Any new programs for developing intraspecies variation in resistance were the beneficiaries of considerable research information that would pave the way for new and probably profitable research. It appeared that blister rust resistance was under genetic control. Resistance already had been isolated by natural selection in Eurasian white pines, and rapidly was being isolated and made available through the application of strong selection pressures in force in heavily rusted stands of North American white pines. Also, while genetic control of resistance appeared not to be as simple as could be hoped, and while important questions remained as to the genetic control, mechanisms, and practical utility of resistance, it seemed that these problems might be resolved by following quite uncomplicated and economical investigative pathways.

The Forest Service's first-phase R&D program for improving blister rust resistance in Inland Empire western white pine benefited greatly from this past research and problem analysis. Indeed, given financing, a reasonably well-qualified research team, continued enthusiastic support from potential consumers, and a little more biological good luck, the program seemed almost bound to succeed.

BEGINNINGS OF THE FIRST-PHASE PROGRAM

Blister Rust Situation by the 1940's

From 1946 to 1950 there remained a large, war-delayed backlog of blister rust control, *Ribes* spp., eradication work in the Inland Empire. The awesome spread of the disease in stands of the susceptible *P. monticola* had accelerated, especially in 1937 and 1941, when the weather was highly favorable to spreading rust (Paine and Slipp 1947). By the late 1940's, infection and damage in all ages of *P. monticola* stands was becoming highly visible throughout the region. Many stands already contained high proportions of rust-killed and multicankered trees. Thus, control work was assuming a more desperate urgency, soon to be reflected in increasing appropriations for Federal and State control or in increasing control assessments levied against the privately owned white pine lands (under State law by the northern Idaho Timber Protection Associations). But while control appropriations were increasing, those for tree disease research (including blister rust research) remained pegged at relatively low wartime levels.

This lopsided situation developed for several reasons. Foremost, a vocal and effective coalition of interested citizens and private white pine landowners was pressing for increased control appropriations, if not for research. White pine stocking and blister rust damage surveys showed that, while rust damage often was severe, because of excess stocking adequate numbers of white pines survived to stock most *P. monticola* stands and to justify control work. And the newly developed herbicides 2-4-D and 2-4-5-T were at hand, promising much more effective and economical eradication of *Ribes* spp. Administation of disease research, however, was well aside from this mainstream of control activity. It was isolated mainly in another Federal bureau (Plant Industry, Soils, and Agriculture Engineering) and division (Forest Pathology) where increased funding was proving to be much harder to come by. Small, field-service units, staffed with forest pathologists from the division, were widely scattered around the West (Portland, Berkeley, Albuquerque, Logan, Fort Collins). These units were already overextended on regional forest pathology problems. They found scant support for taking on any new research related to the white pine blister rust disease. Meanwhile, indirect but strong support was coming from the Northern Rocky Mountain (now Intermountain) Forest and Range Experiment Station whose timber management researchers were acutely aware of the blister rust problem in *P. monticola* and of the research hiatus.

In response to this research vacuum, the Federal agency in charge of blister rust control on western State and private white pine lands—the Division of Plant Disease Control of the Bureau of Entomology and Plant Quarantine (BEPQ-PDC)—organized a western Development and Improvement (D&I) Unit headquartered at Berkeley, Calif. This unit was assigned to develop and improve methods of blister rust control. For the Inland Empire these responsibilities were delegated to a three-man D&I subunit stationed in Spokane with the BEPQ-PDC Office of Blister Rust Control. The subunit also serviced the needs of the Forest Service Region 1 Division of Timber Management. This division worked in six "white pine" National Forests in undertaking blister rust control.

This bureaucratic maze developed largely because of the way various blister rust control and research funds were appropriated on both the State and Federal levels. It was perpetuated because of reorganizational delays inevitable under a rapidly developing blister rust control scene. How this nightmare of a field control organization operated at all is a mystery. But operate it did, under the guidance of some experienced and dedicated administrators. It persisted through 1953 when a national reorganization placed all the Inland Empire control work under a Forest Service Region 1 Division of Blister Rust Control, and all Inland Empire disease research under the Forest Service Northern Rocky Mountain Forest and Range Experiment Station.

Facts and Fancies on the Planning

In 1946, the author was the junior member of the newly established, three-man Spokane D&I subunit. I was stationed in Spokane at the BEPQ-PDC Office of Blister Rust Control, working out of a small laboratory on the eighth floor of the downtown Realty Building. As a forest pathologist, my responsibilities included development of blister damage survey methodology.

From time to time during survey work, I came across rare *P. monticola* individuals that somehow, although growing in heavily blister-rusted stands, had remained free of the rust. Found in 1946, the first of these remarkable trees was full-crowned, dominant, 60 years old, and almost 100 ft (30 m) tall. It was the only white pine crop tree among almost 380, sampled across a heavily rusted 530-acre (215 ha) stand, that was

completely free of either living or dead blister rust cankers (fig. 1). This tree was the more remarkable to me because I had shared in the vicarious pleasures of climbing, examining, and discarding several other such "resistant" selections because of many, hidden but active cankers—much to the chagrin of the hopeful, but earthbound, supervisory personnel below.

Through the next 3 years, 14 more such rust-free individuals were located in five other heavily infected Inland Empire, *P. monticola* stands. Following procedures on selection and testing of *P. strobus* used in Wisconsin, I commenced small cutting-rooting trials in 1949. These trials were housed in a sort of greenhouse that protruded precariously about 4 ft (1 + m) from an eighth floor window of the Spokane lab. Also, with Cumming and Righter's new (1948) publication on controlling pollination in *Pinus* at hand, I climbed selection No. 1, the 100-ft (30-m) tree described above. There, I attempted a controlled self-pollination. Not only did the cuttings fail to root, but the self-pollination failed to produce any filled seeds. However, these abortive trials may have served other much more useful purposes.[3]

Figure 1.—Resistant *P. monticola* selection No. 1; neighboring white pines were multi-cankered or killed by blister rust.

The lack of forest genetics and tree improvement expertise was recognized at once, and the cooperators requested help from another Forest Service unit—the California (now Pacific Southwest) Forest and Range Experiment Station's Institute of Forest Genetics.

The Office of Blister Rust Control, cognizant of the lack of research funds, labeled the new resistance work as "developmental," and requested that the D&I subunit assign the author up to one-third time on the new work. The Northern Rocky Mountain Station also assigned A. E. Squillace, research forester, up to one-fourth time on the work. The Division of Timber Management of Region 1 came up with $5,000 in National Forest blister rust control funds to finance a five-man search for additional rust-free selections. And Dr. F. I. Righter, director of the Placerville, Calif., Institute of Forest Genetics of the California Station, agreed to train Bingham and Squillace in the methodology of controlled pollination and tree improvement. Righter also assigned Forest Geneticist Dr. J. W. Duffield to the training and planning work.

The Placerville training session, held in 1950, constituted the first real meeting of the hastily assembled investigative team of Bingham, Squillace, and Duffield. It was fortuitous that these men were both professionally and personally compatible. We immediately set out to define our problem and the research required for its solution. In those days, research planning procedures were flexible, and much of the problem analysis and study planning work proceeded informally largely by unwritten cooperative agreement. The research team did feel obliged to produce one semiformal document—a magnificent, huge flow chart covering the what, when, and who of interlocking research jobs. The problem analysis drew heavily on the early results of Snell, Riker and coworkers, and of Johnson and Heimburger, as well as on the lucid and farsighted suggestions of Dr. Carl Hartley (1927). You may be sure that the points enumerated in the following section were not nearly so precisely or logically defined or stated. Time and the first few years of field work have polished them.

A Skeleton Problem Analysis and Study Plan

WORKING ASSUMPTIONS

1. Inland Empire *P. monticola* stands included some of the world's most spectacular white pine blister rust epiphytotics. Heavily rusted stands of highly susceptible *P. monticola* had by 1950 undergone 20 to 25 years of exposure to the virulent disease. These stands did, however, contain surviving and completely rust-free individuals. These individuals appeared to be highly resistant phenotypes that were isolated by strong natural selection pressure generated by the epiphytotic rust disease. The "resistant" selections seemed to be just as good (and in the long run proved to be far better) as those already isolated and tested in the *P. strobus* programs.

2. There were two research jobs of the highest priority—verifying genetic control of resistance in *P. monticola*, and determining whether the level of inheritance of resistance in early generation offspring from potentially resistant phenotypes would justify a practical breeding program.

3. Mass vegetative propagation of any resistant *P. monticola* clones would be impractical, neither technologically nor economically attainable. Vegetative propagation would be used only as a research tool or as a means for establishment of clonal seed orchards.

[3]See appendix for anecdote.

4. Aside from the overwhelming problem of susceptibility of existing stands to *C. ribicola, P. monticola* came close to being an ideal, timber-type conifer. It had proved to be eminently manageable; it reproduced naturally and easily, grew relatively rapidly, and competed well in either managed or unmanaged mixed stands (Haig 1932; Haig and others 1941). The wood was light-colored, soft, straight-grained, and easily sanded, glued, or painted. As finish sash and trim lumber, the wood had continued to command the region's highest stumpage and lumber prices (Betts 1940; Matthews and Hutchison 1948). Furthermore, it was more than acceptable as an addition to the region's mixed-species paper pulp output (personal communications, local pulp mills). Thus, it seemed appropriate to confine the major emphasis toward improvement of blister rust resistance of *P. monticola* to the intraspecies breeding option, working mostly within that valuable and locally well adapted species. A secondary emphasis would be the introduction of germ plasm from resistant Eurasian white pines through interspecies hybridization. It appeared that such interspecies work was already well under way at the Placerville Institute of Forest Genetics (Righter 1945; Duffield and Stockwell 1949), at Harvard University (Sax 1947), and in Canada (Johnson 1939a, 1939b; Johnson and Heimburger 1946).

5. Level of inheritance of seed-transmitted resistance had remained obscure and conflicting during the testing of wind-pollinated seedling progenies of resistant *P. strobus* phenotypes—for instance, the results of Riker and others (1943a, 1943b, 1949) vs. those of Johnson and Heimburger as reported by Farrar (1947). Therefore, it would be advantageous to certify male parentage by controlling pollination and restricting it to crosses or selfs among phenotypically resistant *P. monticola* selections. Although we planners at the time didn't know, this same assumption apparently had already been reached by Riker and his coworkers in Wisconsin (Patton and Riker 1958a).

6. To avoid unnecessary delay, controlled-pollination work would be undertaken immediately, directly on the phenotypically resistant *P. monticola* selections in the forest.

7. The difficulty and high cost of this work, and the consequently high value of control-pollinated seed (later estimated at $5,000 to $10,000 per pound or $11,000 to $22,000 per kilogram) would necessitate the development of surefire methods for seed pretreatment to secure good germination and thereafter for minimizing losses of seed and nursery test seedlings.

8. Many more phenotypically resistant selections should be located for undertaking the preliminary and necessary resistance research. As it turned out, we found a total of 58 selections by the time pollination work began in June 1950.

SELECTION CRITERIA

1. Artificial selection work should be directed only toward resistant phenotypes that were reproductively mature.

2. Artificial selection, to be superimposed on the hypothesized fabric of preexisting natural selection, should seek to emphasize the effects of that natural selection. Per-generation genetic gain in resistance should be maximized by restricting selection to those areas and stands that had undergone the stiffest natural selection pressure; this also would minimize the inclusion of selections that were merely chance "escapes" from the disease. For practical purposes, this came down to undertaking artificial selection work only in stands that had undergone more than 20 years exposure to the rust, and where severity of that exposure was attested by multiple cankerings of the average living or rust-killed white pine. It also came down to restricting selection to completely rust-free individuals chosen on the basis of a close, branch-by-branch, internode-by-internode, top-to-bottom examination, for both living and dead cankers.

3. Tandem, index, or other forms of multiple-trait selection toward improving growth rate, branching habit, planting adaptation, and so forth, along with rust resistance might be possible if a sufficiently large nucleus of resistant selections would transmit useful levels of resistance to their seed-propagated offspring. Thus, while overriding importance should be on blister rust resistance, such features as growth rate, or branching habit should be assessed, and the inheritance of these traits followed to the extent possible to gain breeding information from resistance or supplementary progeny tests.

TESTING CRITERIA

1. A reliable assessment of resistance should be obtained in complete, randomized-block progeny tests, if the number of blocks were large enough to iron out effects of unequal rust exposure and other extraneous variables. Requisite numbers of blocks or of test seedlings within blocks were unknown. But for a start, 9 blocks containing 10-seedling family row plots would be used. Later this was upped to 10 blocks and 16-seedling plots but with only moderate gains in experimental sensitivity.

2. To shorten test-rotation years and to minimize requisite numbers of test blocks by increasing uniformity of rust exposure, all progeny tests would be artificially inoculated. Because earlier research had defined the sensitivity of young white pines to the blister rust disease, particularly 1-year-old plants (Clinton and McCormick 1919; York and Snell 1922), probably only 2-year and older test progenies should be inoculated. Assistance would be needed in establishing a satisfactory and repeatable methodology for large-scale artificial inoculations, and this would be sought from Division of Forest Pathology blister rust specialists.

3. The outward appearance and the timing of the various symptoms of the blister rust disease or signs of the blister rust fungus was quite well established on young *P. monticola* plants (Lachmund 1933; Kimmey 1940; Slipp 1949), and routine symptom-sign inspections could be timed and carried out with some confidence. But the outward appearances of any resistance reactions, or the best timing of inspections for them still was ill defined (Riker and others 1943b, 1949). Thus, a more or less continuous, sample inspection schedule would have to be maintained, both to elucidate any new or different resistance reactions and to time inspections for the determination of their significance.

At the close of the Placerville session in early April 1950, two more jobs remained to be done before the program could get under way during the anticipated June pollination season. The first job was to increase the number of rust-free and reproductively mature selections so that an adequate first-year crossing program might be undertaken. As already mentioned, the Region 1 Division of Timber Management had earmarked $5,000 of their blister rust control funds for this job, and the money went to hiring a temporary, five-man, tree-search crew for May and June 1950. This crew, supervised by the author, searched close to 1,000 acres (400 ha) of white pine stands in seven heavily infected areas near places where the blister rust was introduced in 1923–27. By late June, the crew had increased rust-free selections from 14 to 58.

The second job was to purchase control-pollination supplies and to assemble various pollination syringes, pollen extractors, and so forth. For this first, short-notice season, the Institute of Forest Genetics loaned us 500 of their standard, heavy-canvas, acetate-film-windowed pollination bags, as well as serially numbered airplane cloth pollination streamer tags. The rest of the gear was assembled by the research team.

The First Controlled Pollination Season, 1950

About June 15 the D&I team of Squillace, Duffield, and Bingham reassembled at Blister Rust Control (field) Headquarters, Clarkia, Idaho, where we were near most of the 58 rust-free selections. Tony Squillace came from Missoula bringing the godsend of a ramshackle, prewar, carryall vehicle. And Jack Duffield drove from California in D&I boss Harold Offord's car lugging a bulky load of pollination bags and tags from the Institute of Forest Genetics.

Clarkia BRC Headquarters was an age-mellowed, and already long defunct, railroad-logging base camp. It had seemingly numberless barns, sheds, bunkhouses, and warehouses, plus a rectangular "roundhouse" with 15-ft tall (5-m) doors for servicing long-gone logging locomotives and rolling stock. Altogether there was just about one-half acre (0.2 ha) of roofed space where a single winter snow removal required a week's work by a 5- to 10-man crew. The old camp housed an assortment of carpentry, plumbing, vehicle repair, machine, canvas fabrication and repair shops, and other buildings. Such facilities were necessary for supplying up to 1,000 control workers scattered over the St. Joe National Forest area in as many as 50 separate, road or mule-pack tent camps. It also housed a wonderfully supportive group of BRC "overhead" personnel who, through the years, fed (oh, so well) and housed (only one bedbug outbreak) the researchers and helped them in the evenings with everything from assembling pollen extractors to extracting and cleaning seeds. The entire layout was rented for $25 a month from a latter-day and benevolent landlord, Potlatch Forests, Inc. (now Potlatch Corp.); and we were shocked and incensed when, about 1955, PFI doubled the monthly rent in order to meet taxes.

None of us researchers will forget that first and hectic pollination season. It taxed the considerable physical abilities of the young, three-man team near their limits. There were no summer field assistants, but, fortunately, neither were there prescribed limits like 8-hour days or 40-hour weeks.

The team was completely inexperienced in controlled pollination of *P. monticola* under northern Idaho conditions. We installed only about 600 pollination bags and worked in only about 25 trees that had produced male or female strobili—all within 15 miles (25 km) of our headquarters. We found later that with experience we could put in the same hours and amount of work to handle two to three times that number of trees and pollination bags. Three visits to each tree top were minimal the first season—once to detect and bag female strobili and collect pollen, once to pollinate and tag bagged strobili, and once to remove pollinaton bags and check success of pollinations. But with more fruitful trees that bore 100 to 400 female strobili, we found ourselves climbing them 20 or more times.

Three of the worst scenarios we could think of all came true: First, we climbed the tree so prematurely that we were unable to differentiate female strobili from vegetative buds, or that we overlooked the very small and green clusters of male strobili. Second, we bagged the female strobili so early that on rapidly elongating, current season shoots we had to slip the bags out on the shoots one or more times lest shoots become curled up inside the bags. And third, we bagged weak and usually single female strobili on the tree crown's inner and lower branches that most often "pooped-out" (aborted), but not until they reached "buds open" stage and were pollinated repeatedly, only to drop off when we removed the pollination bags.

Indeed, we literally wore out some of these more fruitful trees climbing them so many times. The soft bark on the upper sides of branches in the upper third of the tree crowns was completely crushed and destroyed even by our sponge rubber-soled boots. These trees had to be "rested" for a year or two thereafter.

By the late 1950's Squillace and Bingham, with three or four field assistants, were undertaking 4,000-bag pollination seasons involving over 100 trees scattered along 400 miles (640 km) of backwoods roads, and with relative ease.

Our main problem emerged when we attempted to follow the quite sophisticated methods of Cumming and Righter (1948) for extracting uncontaminated pollens. These methods that worked so well in warm and dry California were beset with serious problems in the relatively cold and damp *P. monticola* pollination season in the northern Idaho woods. When we followed the recommended procedure of washing clusters of male strobili and entering them under water into sterile canvas-topped, metal-funnel-bottomed pollen extractors, it was only the very ripest or often already-pollen-shedding clusters of male strobili that could be induced to shed pollens. These pollens were mostly very damp and soon molded. Prebreakfast and postdinner were heralded by cacophony from us three scientists on the bunkhouse porch when we vigorously rapped with wooden sticks on the metal extractor funnels hoping to shake down enough fresh, if damp, pollen for a day's work. Even the innovative Duffield's pollen extractor air manifold, designed and produced almost overnight in the plumbing and carpentry shop, failed to dry out the stubbornly sodden mass of pollen catkins—and this after a full night of blowing woodstove-heated bunkhouse air up through the bottom of the extractor funnels.

Fortunately, the pollen extractions almost daily provided viable, if damp, pollens that proved to be capable of effecting fertilization. Cones were collected September 6 to 19, 1951, just as they commenced opening. They were spread out by individual crosses in deep wooden, window-screen bottomed drying trays, and racked up ceiling-high alongside the bunkhouse barrel stove. After the author and the volunteer Clarkia BRC overhead crew hand extracted, winnowed, and cleaned the seed[4], the result was as follows: of 93 separate, control-pollinated crosses attempted on 25 different selections, 78 of 83 intraspecies crosses, and 4 of 10 interspecies crosses (all × *P. strobus*), yielded adequate numbers of filled seeds for progeny testing. The gods of fertility had indeed favored us mightily!

Between pollination and cone collection we experienced the usual problems with cone and seed insects, and a few problems with squirrels[5]. Fortunately, Jack Duffield was aware of the insect problem and insisted that we rebag control-pollinated cones their second year; thus, we were on hand to do this job in late April or May, as soon as snow permitted. Even as early as we cone-bagged[6], the cone beetle *Conophthorus ponderosae* Hopkins, and less often two cone moths (*Eucosma rescissoriana* Heinrich and *Dioryctria abietivorella* [Grotė]), would beat us to as many as 25 percent of the cones. But sans bagging, cone insect losses were known to have exceeded 90 percent in certain areas and years (Barnes, Bingham, and Schenk 1962).

By 1951, mostly in the course of other work, we researchers had found 12 more rust-free selections in three other areas. This brought the total to 70, which we considered adequate for preliminary investigations.

Controlled pollination work, however, was continued to 1953 when after 4 years we had nearly 200 *P. monticola*, first-generation (F_1), intraspecies progenies in hand or coming by fall 1954. We considered these 200 progenies to be adequate for preliminary investigations into genetic control and level of inheritance of blister rust resistance. After 4 years, it was evident that there were no practical means by which we could produce a complete diallel cross for testing. Successful crossing of each selection with every other selection would have required many more years of pollination work.

Preliminary Progeny Testing, 1952 to 1959

Controlled pollination work for the 4 years 1950 to 1953 had resulted in about 200 F_1 seed progenies from intraspecies crosses among about 40 of the rust-free parent selections. The seed progenies became available in the 4 seed years, 1951 to 1954, and were sown 1952 to 1955 in 4 successive progeny tests in a small nursery in Spokane, Wash. A "1952 progeny test" was established that spring with seeds from the 1950 controlled pollinations; a "1953 progeny test" in that spring with seeds from the 1951 controlled pollinations; and so forth.

Each progeny test contained several lots of presumably susceptible, control materials. In the 1952 progeny test, control lots were ordinary Forest Service Savenac Nursery *P. monticola* seedlots. Thereafter, controls came from mixtures of wind-pollinated seeds from differently colored cones found in selection area squirrel caches, or from mixtures of wind-pollinated seeds from equal numbers of cones from five or six obviously susceptible (multi-cankered) trees in various selection areas. Many wind-pollinated seedlots collected from the rust-free selections were also included in these progeny tests.

The pollination and progeny test operations are outlined in table 2, using the 1952-sown test as an example. Most of these operations are also detailed in the next several pages.

[4]See appendix for anecdote.
[5]See appendix for anecdote.
[6]See appendix for anecdote.

Seed Pretreatment and Germination

It is difficult to secure consistently good and rapid seed germination in most 5-needled white pines, and *P. monticola* is no exception. To satisfy the species' after-ripening requirements and to break seedcoat and other forms of dormancy, the seeds in our progeny tests received more than 90 days of cold-moist, "stratification" treatment at 35° to 40° F. (1.7° to 4.4° C) in the refrigerator (Larsen 1925).

First, in late January, we cold-soaked the seed in 35° to 40° F (1.7° to 4.4° C) tap water overnight, drained the excess water, and dusted the wet seed with Fermate. Next, for the 1952 seed only, we mixed the wet seed with a minimum of fine, sterilized sand and put this mixture in water-permeable, sausage-casing packets salvaged from used pollination bags. Packets varied in sizes depending on the size of the seedlot. Finally, we laid the seed packets on their sides, one layer thick, between l-inch (2.5-cm) layers of premoistened sphagnum peat, with about 10 layers of seed packets to a bottom-drained but lidded, 10-inch (2.5-cm) diameter × 12-inch (30-cm) tall metal freezer can. These cans then were stored in a 35° to 40° F (1.7° to 4.4° C) refrigerator.

Theoretically the low pH "soil solution" should have been diffused from the wet peat layers into the sand-and-seed-filled packets, suppressing fungal and bacterial action. And the seed could readily be separated from the sand merely by flushing away the fine sand through a seed-retaining sieve. Unfortunately, things didn't quite work out this way. Instead, at the close of the stratification period (over 90 days) and just a weekend away from the proposed April sowing, Tony Squillace and I panicked when we found most of the larger seed packets had become soft bricks with the seed and sand cemented by a dense network of tough hyaline fungal mycelium that was firmly attached to the seed coats. Some of these bricks required an hour or more to dismantle, alternately stirring and spraying, and finally handpicking each seed from the tenacious mat of fungal mycelium. Seedcoats were severely eroded, but most endosperms appeared to be firm and the seed looked and smelled all right. Nevertheless, our hearts were in our throats for fear that we might have negated 2 years of work by our failure to detect and control this fungus problem when periodically aerating and checking moisture level of seed packets.

But again we were lucky; following the April 29 sowing, seedling emergence was 85 percent—a level seldom attained in more than 15 years of subsequent tests. Even so, we hastened to change our seed stratification procedures. For the next few years we substituted very fine, dry, screened sphagnum peat for the fine sand inside the seed packets. This controlled fungal and bacterial activity quite effectively, although many of the moist and expanded peat particles would not flush through the sieve when we were recovering seed at the end of the stratification period. We also increased the stratification period to about 120 days. Effective and safe fungicides such as Captan, permitting the relative ease of naked stratification, were still things of the future.

Table 2.—An outline of pollination and progeny testing operations using the 1952 progeny test as an example

Year	Months	Operation	Seedling age	Months after artificial inoculation
			Years	
1950	June-July	Female strobili of rust-free selections isolated in pollination bags; pollens collected and extracted; bagged strobili pollinated and tagged.		
	July-Aug.	Pollination bags removed and success of pollinations estimated.		
1951	May	Cloth cone bags installed over 2d year conelets.		
	Sept.-Oct.	Mature cones collected and separated according to pollination tags into various crosses; seed extracted, cleaned, and counted; progeny test plans made; and corresponding numbers of 60-seedling progeny test nursery flats constructed, filled with forest soil in tarpaper plant bands, tagged, and stored (see fig. 2).		
1952	Jan.	Seed packeted and cold-moist stratified by crosses.	1	
	April	Progeny test established, sowing 1–4 stratified seeds of each test progeny in each of 9 10-plant-band rows in a 9 complete randomized block design (ultimately toward 90 test seedlings per progeny).		
1953	Sept.-Oct.	Test seedlings artificially inoculated under inoculation tents with sporidia shed from telia on heavily infected *Ribes* spp. leaves (almost exclusively 1953, 5-needle-bundle, secondary foliage present); three outplanting plots cleared, fenced, cultivated and planted with *Ribes* spp. bushes.	2	0
1954	May	Seedlings reduced to 1 per plant band, pruning out all but the centermost.		
	June-July	Seedlings transplanted, 3 rows each with 10 seedlings (30 seedlings of 3 randomized blocks) being outplanted onto each of 3 field plots.		
	July-Aug.	Five-needled, 1953 foliage examined for presence of blister rust needle lesion symptoms.		10–11
	Aug.-Oct.	First natural inoculation of 1953 or 1954 foliage, rust spreading from *Ribes* spp. planted on or occurring near outplanting plots.	3	11–13
1955	July-Aug.	Residual 1953 foliage reinspected for missed or latent needle spots from 1953 artificial inoculation, and 1954 foliage for spots from 1954 natural inoculation; seedling 1953 stem and branch internodes examined for rust bark lesions developing from artificial inoculations; abnormal bark lesions that might represent resistance reactions identified and described, and any seedling deaths caused by rust identified.	4	22-23
1956-1957	July-Aug.	Seedling 1953–56 stem and branch internodes examined for rust bark lesions from artificial and natural inoculation; seedlings classified in various living categories, or as rust-killed; progeny test considered to be essentially complete 4 years after artificial inoculation and with rust from 3 years of natural inoculation visible.	5-6	34-47

In another aspect of seed germination, we were decidedly unlucky in the first, or 1952, progeny test. This was in our reliance on Savenac Nursery to provide us with germinable control seedlots. Four of the five seedlots supplied by the nursery germinated at less than 5 percent, and we suddenly found our progeny tests were essentially without controls. Fortunately the nursery at Haugan, Mont., had sown several other germinable *P. monticola* seedlots in fall 1951, and these were available, as cotyledon-stage seedlings, to replace our four nongerminable lots.

We carefully lifted the small seedlings from four Savenac Nursery lots, discarding any with broken radicles. Seedlings were then rushed to Spokane and transplanted into pencil-sized dibble holes flushed full of a soil slurry. The transplanting was better than 90 percent successful, but unfortunately the transplants remained dwarfy and of lower than expected susceptibility for several years thereafter.

Progeny Testing Cycle

Using the 1952, or first-sown, test as a trial, the progeny testing cycle was devised and altered as we went along. By the end of this first test, we were able to set timing and methodology for the three subsequent preliminary progeny tests. The cycle involved 2 years of nursery and transplanting operations (including one artificial inoculation with pine-infecting *C. ribicola* basidiospores). This was followed by 4 or more years of individual seedling inspections (on field outplanting plots) aimed at detecting presence and development of the disease in foliage and bark, as well as any resistance reactions in the seedling host plants. Actually, beginning with controlled pollination for production of test progenies, the test cycle extended over 8 or more years. Methodology used in the nursery and field plot operations is detailed in the next several pages. Throughout the progeny testing, seedlings were routinely weeded, fertilized, and sprinkler irrigated as necessary in the nursery or field plots.

FIRST YEAR, SEED-SOWING

Stratified seed was sown in late April to early May in a prescribed number of 12- by 20-inch (30- by 50-cm) western redcedar flats each 8 inches (20 cm) deep (fig. 2). These were then plunged to ground line, back to back, in a small Spokane nursery (fig. 3). Depending on the amount of seed available and stratified, one to four seeds of each test progeny were centered or evenly distributed across the forest-soil surface and covered with 0.25 inch (0.6 cm) of white sand, in each of 90 heavy, open-ended tarpaper plant bands 2 inches by 2 inches by 8 inches (5 cm by 5 cm by 20 cm)that were soil-filled and arranged randomly as nine 10-band rows scattered through the 60-band flats. This experimental design was devised by Tony Squillace; it included nine complete randomized blocks, each block containing one randomly located, 10-seedling row-plot (the basic test replicate) of each test progeny.

SECOND YEAR, ARTIFICIAL INOCULATION

From mid-September to early October, all test seedlings (2 years old) were artificially inoculated once for 72 hours. This procedure was devised and tested in 1951 and early 1952 by cooperating forest pathologists J. W. Kimmey and C. D. Leaphart, respectively, of the Berkeley, Calif., and Missoula, Mont., field offices of the Division of Forest Pathology. Inoculations took place at the end of the test seedlings' second growing season when the seedlings' foliage was almost exclusively composed of 5-needle, secondary needle bundles.

Inoculation proceeded inside shaded, presoaked, and intermittently fogged canvas inoculation tents. Inoculum was mature but usually ungerminated *C. ribicola* telia borne on the undersides of *Ribes hudsonianum* Richards var. *petiolare* (Dougl.) Jancz. and/or *Ribes viscosissimum* Pursh leaves. The infected leaves were collected on the woody *Ribes* spp. branches, the freshly cut lower ends of which were plunged into the wet nursery soil between the test seedlings (fig. 4).

Telial formation on the infected *Ribes* spp. leaves already had been triggered by falling autumn temperatures in the mountains of northern Idaho and northwestern Montana where we collected the inocolum; and when it was cool but dry, we could collect leaves with ungerminated telia. Thereafter, we tried to maintain low temperatures of 55° to 65° F (13 ° to 18° C) inside the shaded and evaporatively cooled inoculation tents. At the same time we tried to maintain relative humidities

Figure 2.—Western redcedar flat containing sixty 2- by 2- by 8-inch (5- by 5- by 20-cm) tarpaper plant bands, pretagged to show the identities of six different 10-seedling rows of test progenies along the upper leading edge.

Figure 3.—Double rows of cedar flats containing soil-filled plant bands, in the Spokane blister rust nursery, spring 1952. Volunteer helpers Dick Watt (foreground) and Cap Larsen (checkered coat) are sowing *P. monticola* seeds on the surface of each plant band, following a guide card to locate the nine flats and 10-seedling rows therein for the particular test progenies, then covering the seeds in the rows with sand.

Figure 4.—*Ribes* spp. branches with germinating *C. ribicola* telia on undersides of leaves. The branches were stuck in wet soil in and around *P. monticola* test seedlings in two Spokane nursery beds. Central row of fog nozzles over the nursery bed aisle helped maintain high relative humidity inside the inoculation tent.

near the 100 percent level by fogging inside the tents and spraying tents with water from the outside. If these conditions were ideal, after about 18 hours the teliospores of the telial columns would have germinated, basidia and basidiospores would have formed, and the basidiospores would be starting to shed. Shedding of basidiospores would continue for most of the remaining time in the 3 days of inoculation (Hirt 1942).

Basidiospore casts were not estimated in 1953 when the first or 1952-sown test was inoculated, but basidiospore casts were estimated thereafter from 1954 to 1956. Estimates of the cast, as collected on vaseline-coated slides, ranged from 6 to 53 basidiospores per square millimeter, and estimating that the average 2-year-old *P. monticola* seedling presents a 1 000 mm^2 foliar target, then the foliage of the average test seedling could have intercepted 6,000 to 53,000 basidiospores.

Artificial inoculation proved to be the least controllable, and thus the most critical, operation of the entire test cycle (Bingham 1972; Patton 1972). This was mostly because we were dependent upon naturally produced inoculum from the field, or because we were inoculating large numbers of test seedlings outdoors in the nursery. In both places we were at the mercy of the weather. Cool, wet weather for a day or two preceding and during the inoculum collection usually meant that most of the teliospores in *C. ribicola* telial columns had germinated, produced basidia and basidiospores, and already had shed most of their basidiospores. Conversely, hot, dry weather during the 3-day nursery inoculation usually meant that we had off-and-on, nighttime-only basidiospore production and infection of test seedling foliage. This happened because we were unable to maintain the required low temperatures and high relative humidities in the tent-covered nursery beds during all the daytime hours.

THIRD YEAR, OUTPLANTING TEST SEEDLINGS

Already, at the age of 2 years, the test seedlings grown in the Spokane nursery were becoming crowded (fig. 5). We lacked transplanting space there, yet feared possible wildfire losses on any single field outplanting site. So we cleared, cultivated, and fenced three geographically separated outplanting sites in 1953, the year before the first transplanting. These sites were situated in heavy blister rust infection centers, one along Elk Creek about 3 miles (5 km) above Elk River in Idaho, one just across the St. Maries River west of Fernwood, Idaho, and one about 5 miles (8 km) up Randolph Creek northwest of Saltese, Mont. Each of these plot sites also contained a 1951 and 1952 planted test of grafted, clonal lines from 36 of the earliest found rust-free selections (Bingham 1966).

Figure 5.—Two-year-old *P. monticola* seedlings, showing root growth between plant bands. For transplanting, rows of seedlings were separated, lengthwise and crosswise, by slicing with a sharp butcherknife. (Photo courtesy Francois Mergen)

Three of the nine randomized blocks of test seedlings (in other words, 30 of the test seedlings) were outplanted onto each field plot at the start of their third growing season, in June and early July. Transplanting was done by lifting the 60-plant band flats from the Splkane nursery, transporting them to the field site, dismantling the flats, cutting both ways between the rows of plant bands that were by then interconnected by root growth (fig. 4), and finally by sliding the still-tubed seedling into a transplanting hole. These holes had been precut along 9-foot (2.7-m) low row-plot lines, each hole spaced 1 ft (30.5 cm) apart along a board template. The soil plugs, just the size of each tubed seedling, had been cut and removed from the hole using a soil plug cutter (fig. 6) designed by the D&I Unit's mechanical engineer, John F. Breakey.[7] Survival of the seedlings, enhanced by banding and sprinkler irrigation, reached almost 100 percent.

Squillace's experimental design, established in the nursery at 2-inch (5-cm) square seedling spacing was merely expanded six times and carried into the field intact at 1 ft (30.5 cm) square spacing. Each seedling was maintained in the field in the same relative position as in the 10-seedling nursery rows, or in relation to the adjacent nursery rows and seedlings as they occurred in the nursery flats. Flats had been tagged with the randomly drawn test progeny identities (such as female 58 × male 17, 58 × Wind, Control C, and so forth). Once the 50-lb (23-kg) flats had been transported onto the outplanting plots,

[7]See appendix for anecdote.

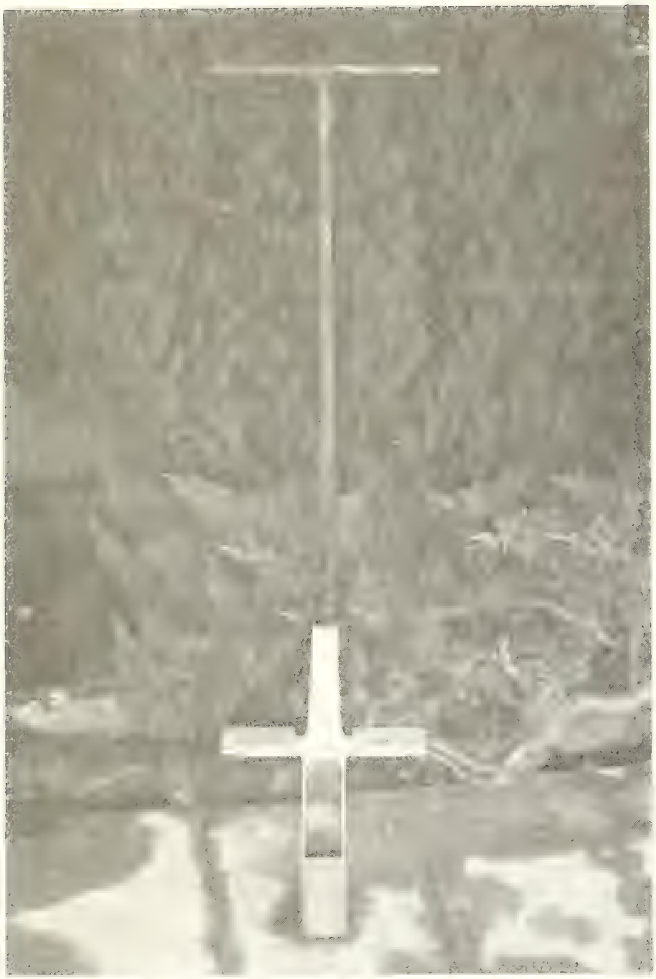


Figure 6.—John Breakey's soil plug cutter. It removed a 2- by 2- by 8-inch (5- by 5- by 20-cm) soil plug for transplanting plant banded *P. monticola* seedlings.

they were placed near the six row-plot stakes that corresponded to the flat and progeny identities. The flats were then opened along one side as shown in figure 5, each successive row-plot of 10 seedlings was removed from the flat, and the individual seedlings were transplanted into the precut holes in sequence of rows and by position of seedlings within the rows. Row-alinement was maintained by extending the 9-ft (2.7-m) plug-cutting template board enough so that both ends lined up with a row-plot stake in the row being planted and the corresponding stake in the next bed over.

To augment artificial inoculation should infection therefrom prove to be light, we had already planted rows of *Ribes viscosissimum* bushes 1 ft (30.5 cm) off either end of the row plots.

This exact spacing of seedlings and progeny row-plots proved to be useful methodology. Twenty-five years later we could identify each progeny and the individual seedlings therein with certainty. And we could map the relative success of artificial inoculations. Lightly or uninfected portions of the seedling beds soon became apparent in the field, and the underexposed seedlings therein could be recognized and eliminated from resistance investigations.

In early July 1954, Tony Squillace and I, along with summer assistants George Blake and Eugene Amman, were transplanting the last third of the 1952 progeny test seedlings onto the relatively high-elevation Randolph Creek, Mont., plot. Patches of snow were still visible on the mountainside above the plot site. Our first job was to hand-carry some 135 flats, each more than 50 lb (23 kg), downhill 50 yards (45 m) from the road, across Randolph Creek on a slippery footlog, and then 150 yards (135 m) up a steep hillside onto the cleared plot site. For the safety of the seedlings, we carried the angular and difficult-to-balance flats against our bellies with the seedlings a scant 12 inches (30 cm) beneath our eyes. From this particular angle, we soon noticed that the foliage of most of the seedlings was liberally sprinkled with a multitude of yellow spots or flecks (fig. 7). This was the first time we had observed this needle-spot phenomenon, and because it offered a good excuse to rest, a hasty, plotside consultation ensued. Sure enough, the needle spots resembled those described and pictured in the literature as the first, visible symptoms of the blister rust disease. We had probably not noted the spots while planting the two low-elevation plots because seedling flats for those plots had been removed from the relatively warm Spokane nursery as much as a month earlier than the Randolph Creek seedling flats.

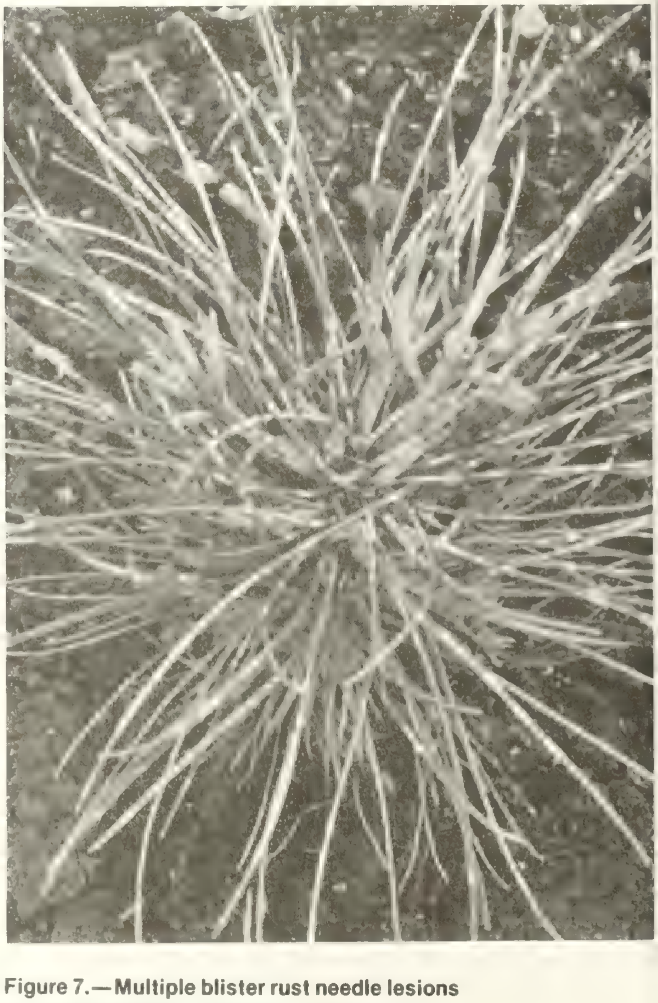


Figure 7.—Multiple blister rust needle lesions on a susceptible *P. monticola* seedling that is starting its third season of growth, about 11 to 12 months after artificial inoculation at Spokane.

Variation in frequency of needle spots seemed to be associated with different test progenies and parents, and, undeniably, we were quite excited. What wonders we had wrought! Here was our first vision of genetic control of resistance, if only we could decide how to measure it! We were mighty tired from the long hours and weeks of transplanting, but the only decision that could be made was to immediately start another round of the field plots to gather needle-spotting data.

THIRD YEAR, INSPECTION FOR FOLIAR INFECTION

We were quite hesitant at first to designate any foliar lesion as a bona fide blister rust symptom. After all, all we had to go on were a few written descriptions and line drawings or black and white photos (Clinton and McCormick 1919; Spaulding 1922; York and others 1927; Pierson and Buchanan 1938). Furthermore there were similar, yellowish-green discolorations associated with various mechanical injuries (such as cracked, broken, or insect-chewed needles). So we made microscopic examinations of frozen thin sections that disclosed rust hyphae and especially the massive rust pseudostromas (fig. 8) that underlay genuine rust foliar lesions. With time and experience, we were soon accurately identifying the quite discrete, circular, lemon to orange-yellow blister rust needle spots.

One measure of the authority of our diagnoses can be obtained from the performance of the presumably nonresistant control seedlings. Here, among seedlings of five different control lots used in the 1952 progeny test in July and August 1954, we diagnosed 235 seedlings as having blister rust foliar lesions on foliage of the 1953 internode. Within 2 years, 95 percent of these infected seedlings had produced one or more typical blister rust cankers in bark of the 1953 internode. Ultimately, 99 percent became cankered on 1953 or later internodes. On the other side of the ledger, among the total of 7,523 controlled and wind-pollinated seedlings of rust-free selections inoculated on 1953 foliage, 6,293 were found to be spotted in 1954 and 1955 examinations. Only 303 more seedlings later developed needle spots or cankers on the 1953 internode. We either missed spots, or there were none on less than 5 percent of the infected trees.

It can be inferred then that in the 1952 progeny test, the single fall 1953 artificial inoculation was quite successful. In fact, of the 7,523 controlled and wind-pollinated seedlings of rust-free selections that were inoculated, 6,293 or 84 percent were designated as needle-spotted 22 to 23 months later. However, we detected variations in the degree and uniformity of artificial inoculation in two respects. First, there was more than 20 percent difference between the foliar infection from a first inoculation run in blocks 1 to 6, and that from a second run in blocks 7 to 9. Second, the rust epidemic maps disclosed that seedlings in certain parts of the nursery beds—notably on outside or end rows—were not as heavily or completely spotted. Fortunately, over time, natural inoculation tended to iron out these differences. But over the years, making improvements in inoculation methods as we could, we never were able to eliminate such sources of variation (as shown by fig. 9, which maps intensity of needle-spotting in the 1964 progeny test).

Another thing that continued to plague us over the years was our difficulty in diagnosing needle spots on weak or runty

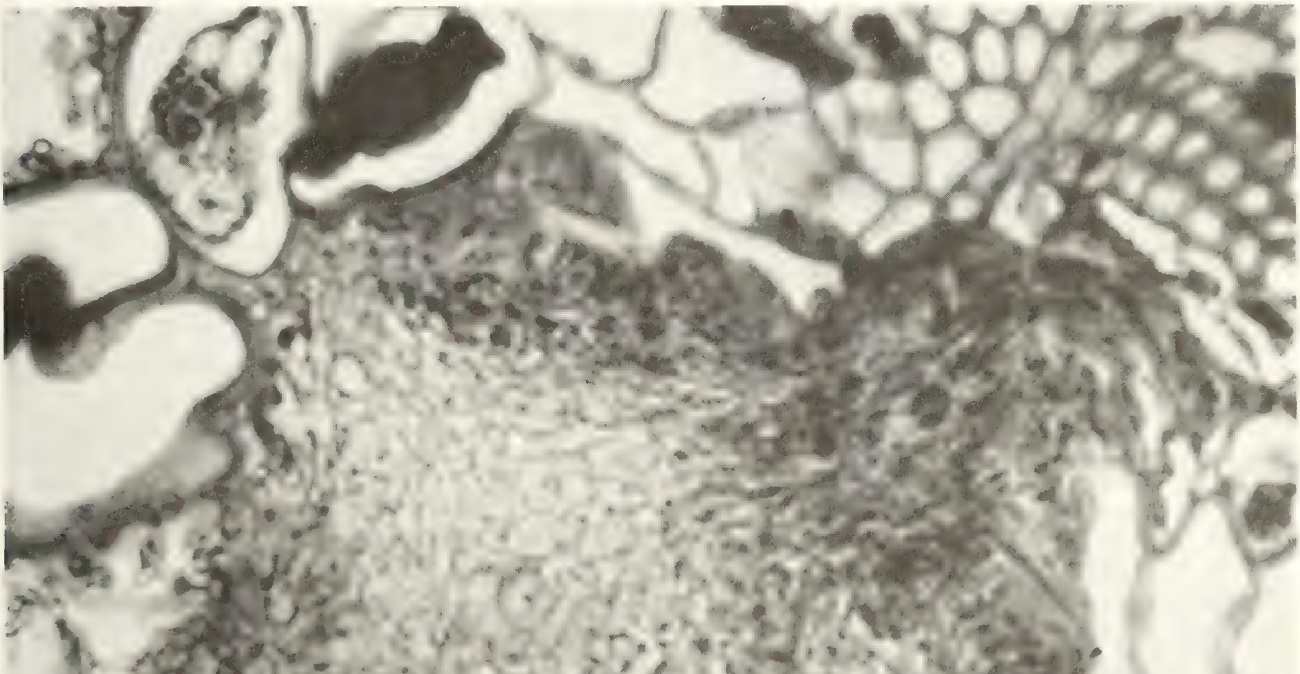


Figure 8.—Frozen section showing the massive pseudostroma of entwined *C. ribicola* mycelium usually found underlying a blister rust needle spot on *P. monticola*, about 11 to 12 months after inoculation.

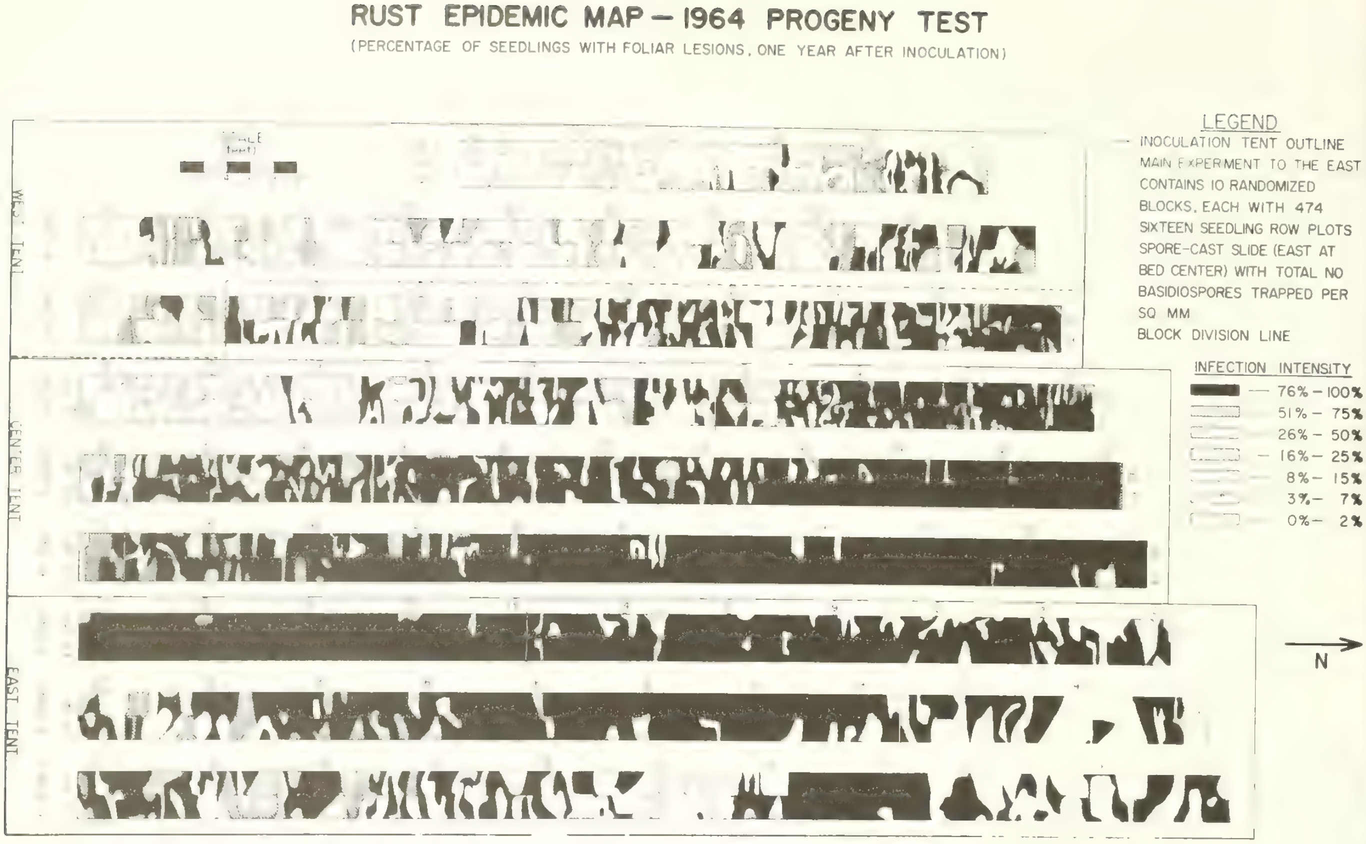


Figure 9.—Variation in percentage of seedlings infected with foliar lesions one year after artificial inoculation, 1964 progeny test.

seedlings, especially those with yellowish foliage. Often the runty seedlings had produced only one or a few bundles of second-year needles, and trying to distinguish lesions on the short and often discolored needles gave questionable results. This was the case with our foliage-lesion examinations on the normally more yellow-foliaged *P. strobus* progenies or on the somewhat yellowish-foliaged *P. monticola* × *P. strobus* hybrid progenies.

Needle spot inspection methodology, improved in several ways since the first (summer 1954) inspection, proceeded along two lines. First, each test seedling was rated either as spotted or spot-free. Second, each test progeny was scored on spot frequency—that is, the number of needle spots on a foliage sample involving a given number or lineal length of needles. Initially, we estimated spot frequency from a sample of 450 needles (contained in the 90 topmost 5-needle bundles) per progeny. But later, to eliminate differences in the total length of needles, we sampled the portions of the needles of the one to four topmost 5-needle bundles that lay inside a 3-inch (7.6-cm) diameter wire ring; this ring was centered about the seedling stem and held in place by a single, stiff wire leg poked into the ground.

During the shakedown period when we were first attempting to assess intensity of foliar infection, we tried unsuccessfully to adapt some cereal rust resistance technology to our tests. This was the use of subjective classes: spot-free = Class I; about 1 to 5 spots = Class II; about 6 to 25 spots = Class III; and so forth. This is similar to schemes still in use for rating severity of uredial infection on cereal leaves and stems. However, we found no statistical correlation between average spot-intensity class and the needle spot frequencies per foliage sample as outlined above. It should be pointed out here that our pine seedlings probably were far more variable in respect to size of foliar target than were the cereal seedlings. A given *P. monticola* seedling, in fact, might have more than 10 times the length or surface area of needles as might another; and one *P. monticola* progeny might have two to five times or more the length or surface area of needles as might another. Thus, the subjective classification schemes that held much promise for simplifying and shortening examinations had to be abandoned.

FOURTH YEAR, FOLIAR AND BARK INSPECTIONS

During the fourth year, we conducted a second inspection for foliar infection and a first inspection for bark infection. This was in July to early August, 21 to 22 months after artificial inoculation and 10 to 11 months after first natural inoculation. Seedlings were 4 years old.

Each test seedling was reinspected as follows:

1. For "old" needle-spots (presumably persistent from the previous year) on the artificially inoculated, second-year foliage still being retained on the seedlings.
2. For new needle-spots on the second-year needlage of previously uninfected seedlings (either latent from the artificial inoculation, or new from natural inoculation on the plot site).
3. For new needle spots on the seedling's third-year needlage that had to have come from natural inoculation.
4. For blister rust bark lesions (cankers) and any resistance reactions thereon.

Over the years it became apparent that natural inoculation, even from concentrations of planted *Ribes* spp. bushes, was at best a slow and irregular process, varying widely by year and outplanting site. For instance, with the 1952 progeny test, the 1955 examinations disclosed that there were 217 of 2,513 seedlings on the Elk Creek plot site that had new spots on 1954 foliage. These had to arise from natural inoculation because the 1954 foliage had not yet been produced when the seedlings were artificially inoculated in 1953. Meanwhile, on the Fernwood and Randolph Creek plot sites, numbers of naturally inoculated seedlings were 97 of 2,572 and 15 of 2,438, respectively. The continuing natural inoculation, however, did prove to be useful for "filling out" infection in those portions of the nursery beds where the level of seedling infection had been unsatisfactorily low. Nevertheless, it was abundantly evident that a progeny testing regime relying mostly on artificial inoculation was by far the more efficient process.

FIFTH AND SIXTH YEARS, BARK INSPECTION

We conducted the second and third inspections for bark infection in July and early August of the fifth and sixth years. This was 3 to 4 years after artificial inoculations, and after 2 to 3 years of natural inoculation. Seedlings were 5 to 6 years old. We looked for any blister rust bark lesions (cankers) and any resistance reactions thereon.

SEVENTH AND EIGHTH YEARS, BARK INSPECTIONS

Our fourth and fifth inspections for bark infection were in July and early August of the seventh and eighth years. This was 5 to 6 years after artificial inoculation, and after 4 to 5 years of natural inoculation. Seedlings were 7 to 8 years old.

Bark canker and resistance reaction examinations continued as in the preceding years. These inspections were only carried out for the four preliminary progeny tests because thereafter it became apparent that results changed very little after the third year of such inspection. Also, a final and confirmatory inspection was made in 1966, 10 to 13 years after artificial inoculation of seedlings 12 to 15 years old. This examination did not change the above conclusion.

RESULTS FROM THE PRELIMINARY PROGENY TESTS

Of the four preliminary tests sown between 1952 and 1955, the first (1952) contained the widest array and greatest number of controlled and wind-pollinated test progenies, received one of the more effective artificial inoculations, and provided the most meaningful long-term results. Thus, the results outlined here come almost entirely from this 1952 test. They are quite representative, however, of the other three tests.

For the 1952 test, results were obtained in the course of annual rust examination made between 1954 and 1958 (at test seedling age 3 to 8 years), followed by a confirmatory examination in 1966 (seedling age 15 years).

Through 1957, attrition due to nongerminable seeds, damped-off seedlings, and older seedlings dying from known or unknown causes other than blister rust, had reduced the number of seedlings in the average test progeny to 81. Thereafter, however, there were only minor seedling losses from such extraneous causes.

Genetic Variation in Foliar Infection

Because of experiences of Clinton and McCormick (1919), Spaulding (1922), York and Snell (1922), and other early workers with young *P. strobus* seedlings, we expected to see some blister rust foliage lesions about 1 year after artificial inoculation. We were unprepared, however, for the spectacular effects of such inoculation on 2-year-old *P. monticola* seedlings. Numerous large, vigorous, and many-needled seedlings bore literally hundreds of blister rust needle spots, often coalescent along their needles (fig. 7).

Across the entire 1952-sown test 10 to 11 months after artificial inoculation, we found an average of 177.5 needle spots per 450 needles sampled. This amounted to about one spot for each 2.5 needles, so that if the average seedling had 15 to 25 bundles of needles it probably also had about 30 to 50 needle spots.

Thus, the artificial inoculation had been a resounding success; but we wondered if we might not have seriously overexposed test seedlings to blister rust, perhaps eclipsing some of the forms of resistance that might be present.

The first evidences of blister rust resistance concerned parent-associated variation in (1) the percent of test progeny seedlings that exhibited needle spots, and (2) the number of needle spots found on a 450-needle sample of the seedlings in various test progenies. These two evidences of resistance are apparent in the summarized needle spotting data for the 1952 test (tables 3 and 4).

We could hardly wait to assemble such impressive tables as 3 and 4, but once we had, about the first thing we noted was how inefficient for characterizing the nature and extent of transmitted resistance had been our hit-or-miss mating scheme. Thus, selections such as parent tree numbers 19, 20, or 58 that had borne large numbers of control-pollinated strobili, plus a few other selections such as parents 25 or 30 that had borne phenologically early and abundant pollens, were overrepresented in the progeny test with 9 to 19 control-pollinated test progenies apiece. Meanwhile, other selections such as 10, 15, 23, 27, 28, 29, 34, 38, and 45 (almost 40 percent of the 23 selections tested) were underrepresented, having only 1 to 3 control-pollinated test progenies because they had borne few female strobili or phenologically late or scanty pollens.

Furthermore, mean parental line performances (here represented by the mean control-pollinated progenies of the next to the bottom lines of tables 3 and 4) were not comparable, for whenever there were more than 1 progeny in the parental line, the lineage, other than line parents, varied. For example, parents number 10 and 15 each were represented in the progeny test by 3 control-pollinated crosses. Yet 4 of the 6 crosses (19×10, 20×10, 15×1, and 15×30) were unrelated other than by line parents 10 and 15, and only 2 of the 6 crosses (25×10 and 15×25) were useful for estimating relative performance of the 2 parents. Thus, the mean control-pollinated progenies of parental lines 10 and 15 (respectively with 80.3 and 71.6 percent of their test seedlings bearing blister rust needle spots, next to bottom line table 3; or with 186.7 and 131.0 spots, next to bottom line table 4) could not be expected to appraise very well the relative ability of parents 10 and 15 to transmit resistance, either in respect to each other or to the other 21 parents in the test.

Table 3.—Percent of test progeny seedlings having one or more blister rust needle lesions on 1953, 5-needle-bundle foliage 11 months after artificial inoculation, 1952 progeny test[1]

Male parent	Female parent																						
	1	10	15	16	17	18	19	20	21	22	23	24	25	27	28	29	30	34	37	38	39	45	58	Wind
1			70	88			76	80		74						(74)	78		70[5]					
10							84	78[5]					79											
15	(70)												(72)				(73)							70
16	(88)						74	79	(62)		71		(90)				(72)						84	67
17							81		44	72	55		(74)				(71)		66				72	53
18							78						74				(73)						72	74
19	(76)	(84)		(74)	(81)	(78)	73	(79)	(39)	(73)		(78)[5]			(76)	(84)	(90)	(82)	(35)[5]	69	(89)	52	(70)	76
20	(80)	(78)[5]		(79)			79			(89)		(54)		81			(73)				(84)			69
21				62	(44)		39						60				66		(68)				56	32
22	(74)				(72)		73	89		54[5]			(84)			(88)	(77)						82	84
23				(71)	(55)																			64
24							78[5]	54													69		60	68
25		(79)	72	90	74	(74)			(60)	84							80[2]		75[5]				73	64
27								(81)																74
28							76																	66
29	74						84			88													71	
30	(78)		73	72	71	73	90	73	(66)	77			80[2]				56[5]		(80)		83		74	77
34							82																	
37	(70)[5]				(66)		35[5]		68				(75)[5]				80						67	
38							(69)																	
39							89	84				(69)					(83)				68		64	44[5]
45							(52)																	
58				(84)	(72)	(72)	70		(56)	(82)		(60)	(73)			(71)	(74)		(67)		(64)		81	72
Wind[3]			(70)	(67)	(53)	(74)	(76)	(69)	(32)	(84)	(64)	(68)	(64)	(74)	(66)		(77)				(44)[5]		(72)	57[4]
No control crosses	8	3	3	8	8	4	19	9	7	9	2	4	10	1	1	4	14	1	7	1	6	1	13	16
Average percent infection	76.2	80.3	71.6	77.5	66.9	74.2	72.9	77.4	56.4	77.0	63.0	65.2	76.1	81.0	76.0	79.2	74.7	82.0	65.8	69.0	76.2	52.0	71.2	65.9

Grand average for control pollinated crosses: 72.2

[1]The mean test progeny contained an average of 81 test seedlings distributed over all 9 randomized blocks. The number of test progenies (160) shown below in the body of the table, represents an artificial doubling of the 80 progenies actually tested; the values for the reciprocal crosses are added in parentheses.
[2]In this case the reciprocal crosses actually were made, the value here being the average of the 2 crosses.
[3]These values for wind-pollinated progenies are not included in the average percentages.
[4]The cross wind × wind is the average value for the 5 control lots.
[5]Based on a total of only 14 to 26 seedlings, these represented in only 2 to 6 of the 9 randomized blocks.

Table 4.—Number of blister rust needle lesions on a 450-needle sample of 1953 foliage 11 months after artificial inoculation, 1952 progeny test[1]

Male parent	Female parent																						
	1	10	15	16	17	18	19	20	21	22	23	24	25	27	28	29	30	34	37	38	39	45	58	Wind
1			120	202			116	163		258						(153)	89		49[5]					
10							256	102[5]					202											
15	(120)												(155)				(118)							128
16	(202)						178	277	(232)		162		(239)				(217)						232	187
17							178		57	186	89		(132)				(216)		80				53	74
18							173						148				(209)						77	253
19	(116)	(256)		(178)	(178)	(173)	128	(267)	(37)	(163)		(101)[5]			(131)	(208)	(402)	(102)	(113)[5]	249	(190)	135	(77)	252
20	(163)	(102)[5]		(277)			267			(350)		(176)		235			(260)				(251)			183
21				232	(57)		37						101				137		(167)				77	74
22	(258)				(186)		163	350		333[5]			(233)			(269)	(262)						154	260
23				(162)	(89)																			194
24							101[5]	176													284		148	95
25		(202)	155	239	132	(148)			(101)	233							162[2]		131[5]				77	211
27								(235)																406
28							131																	122
29	153						208			269													90	
30	(89)		118	217	216	209	402	260	(137)	262			(162)[2]				510[5]		(205)		359		245	87
34							102																	
37	(49)[5]				(80)		113[5]		167				(131)[5]				(205)						133	
38							(249)																	
39							190	251				(284)					(359)				247		269	109[5]
45							(135)																	
58				(232	(53)	(77)	77		(77)	(154)		(148)	(77)			(90)	(245)		(133)		(269)		152	147
Wind[3]			(128)	(187)	(74)	(253)	(252)	(183)	(74)	(260)	(194)	(95)	(211)	(406)	(122)		(87)				(109)[5]		(147)	142[4]
No control crosses	8	3	3	8	8	4	19	9	7	9	2	4	10	1	1	4	14	1	7	1	6	1	13	16
Average number spots/450 needles	143.8	186.7	131.0	217.4	123.9	151.8	168.6	231.2	115.4	245.3	130.5	177.2	158.0	235.0	131.0	180.0	242.2	102.0	125.4	249.0	266.7	135.0	137.2	173.9

Grand average: 181.1

[1]The mean test progeny contained an average of 81 test seedlings distributed over all 9 randomized blocks. The number of test progenies (160) shown below in the body of the table, represents an artificial doubling of the 80 progenies actually tested; the values for the reciprocal crosses are added in parentheses.
[2]In this case the reciprocal crosses actually were made, the value here being the average of the 2 crosses.
[3]These values for wind-pollinated progenies are not included in the average percentages.
[4]The cross wind × wind is the average value for the 5 control lots.
[5]Based on a total of only 14 to 26 seedlings, these represented in only 2 to 6 of the 9 randomized blocks

Nevertheless, it was encouraging to note in table 3 that seedling progenies of a few parents appeared rather consistently to be resisting foliar infection. The 4 to 8 progenies each of parents 17, 21, 24, and 37 seemed to stand out in this respect. Conversely, other parents such as numbers 1, 16, 20, 22, 25, and 39 rather consistently produced progenies that appeared to be quite susceptible. Thus, there appeared to be general combining ability (GCA) for both parts of the host's resistance: susceptibility system. There also appeared to be additivity in the system, for when we had crossed parents both notable for producing progenies low (or high) in percent of needle-spotting, then the resulting progenies averaged even lower (or higher) in respect to the grand mean test progeny than had the parental line mean progenies.

Finally, some test progenies (for instance 19 × 21 or 19 × 37) seemed to demonstrate specific combining ability (SCA) for resistance to needle-spotting, since the values for percent spotted (39 and 35 percent, respectively) were well below those expected on the basis of the average progenies of parents 19, 21, or 37.

These promising features of the resistance system were emphasized even more by data on needle spot frequency (table 4). The data show that 3 of the 4 parents that exhibited good GCA for resistance in respect to needle spotting (specifically numbers 17, 21, and 37), plus parents 1 and 58, exhibited GCA for low frequencies per 450-needle samples. Meanwhile, 4 of the 6 parents that exhibited GCA for susceptibility (specifically numbers 16, 20, 22, and 39) also exhibited GCA for high frequencies per 450-needle sample. Again, progenies such as 19 × 21 (37 spots per 450 needles) and 58 × 25 (77 spots per 450 needles) seemed to demonstrate SCA for low frequency. Again there appeared to be additivity in the system (compare the 8 chance crosses including low spot frequency parents numbers 1, 17, 21, 27, and 58; that is, crosses 37 × 1, 37 × 17, 21 × 17, 21 × 37, 58 × 17, 58 × 21, 58 × 37, and 58 × 58). Each of the crosses exhibited lower than average spotting frequency within parental lines, and especially against the grand mean control-pollinated progeny.

In his review of this paper Tony Squillace pointed out the possibility that spotting frequency might simply be inherited. He noted that when, from the data of table 4, he assigned the genotypes homozygous dominant susceptible (SS, to certain parents such as numbers 10, 16, 20, and 27), homozygous recessive resistant (ss, to certain parents such as 17, 21, and 58), or heterozygosity (Ss, to certain parents such as 1, 15, 19, and 37), then the various crosses of table 4 showed an orderly decrease in spotting as one progressed from the cross SS × SS to the cross ss × ss, as below. He computed average degree of dominance as near 0.75.

Proposed genotype of cross	Number of crosses	Average number of spots/450 needles
SS × SS	9	257.0
SS × Ss	22	213.2
SS × ss	9	208.9
Ss × Ss	14	131.1
Ss × ss	13	106.6
ss × ss	3	62.3

This interested us because Hoff and McDonald (1980) had tested similar analyses and reported similar findings for a later progeny test. They stated that while a single (major) gene hypothesis did not fit the resistance-susceptibility system, nevertheless, single incompletely dominant gene hypothesis fit the system best.

Tables 3 and 4 also brought out the anomalous performance of many wind-pollinated progenies of rust-free parental selections. Of seedlings needle-spotted in the 16 wind-pollinated progenies of table 3, the average percent was 65.9, while seedlings of the 59 control-cross-pollinated progenies of the same 16 parents averaged 72.4 percent needle-spotted. And the average number of needle spots per 450 needle sample for the 16 wind-pollinated progenies of table 4 was 173.9, while the 59 control-pollinated progenies of the same 16 parents averaged 178.6 per 450 needles.

Thus, it appeared that on the average the wind-pollinated progenies of rust-free selection were slightly more resistant than progenies from controlled crosses between two rust-free selections. This was counter to our expectations. We assumed that with mainly outcrossing and panmixis under wind-pollination, the rust-free selections would have been pollinated by a variety of susceptible neighbors. An unexpectedly great number of selfs in the wind-pollinated progenies was the only logical theory we could advance to explain these aberrancies. However, the height difference (only 0.009 ft or 2.7 mm) between the average wind- and control-pollinated progenies of the 16 parents belied any such theory.

The apparently good performance of the five ordinary nursery control progenies was even more surprising. We thought these materials were the most susceptible in the progeny test, yet they proved (in tables 3 and 4) to contain over 15 percent fewer spotted seedlings and to bear almost 40 fewer spots per 450 needles than the grand mean control-pollinated test progeny. However, there was an acceptable explanation for this apparently low susceptibility. Four of the five original control lots had germinated at levels of only 1 to 5 percent in the nursery beds in 1952, and the fifth lot, less than 15 percent. The four worst lots were replaced completely by transplanting later-germinating and thus somewhat younger and smaller seedlings from Savenac Nursery, and the 55 percent of vacant plant bands of the fifth lot were replaced by transplanting from a standby bed of the same control lot.

Two years later when test seedlings were inoculated (in the fall before needle spotting was assessed in the 3-year -old seedlings) these 5 control lots averaged only about two-thirds the height, about 2.01 inches (5.1 cm), of the average control-pollinated progeny, or about 2.99 inches (7.6 cm). In general they also appeared to be weaker and more runty. Paired "t" test showed that the shorter and less vigorous transplants were indeed a different population than normal seedlings; they were significantly (1 percent level) less infected and less heavily spotted than normal seedlings, following the old rule what weak plants are relatively poor suscepts for obligate parasites.

Thus, we thought that the aberrant performance of wind-pollinated and control progenies would disappear with time as latent infections from the 1953 artificial inoculation and new infection from 1954 or later natural inoculations began to appear.

Information in tables 3 and 4 made it apparent that for the same money and work we would have been better off and further along had we consistently employed some factorial mating scheme (for instance, a scheme wherein each rust-free parental selection had been crossed with 4 to 8 other "tester" selections). Alternatively, was it possible to simulate such a factorial mating scheme, using certain of the matings we had entered as test progenies in the 1952 progeny test? Luckily, such a simulation appeared to be possible using the five most frequently crossed selections (numbers 19, 20, 25, 30, and 58) as

"testers" and the nine other frequently crossed selections (numbers 1, 16, 17, 18, 21, 22, 24, 30, and 37) as the other parents. In this simulated 5 × 9 factorial cross there would be only 9 (of 45) cells, or crosses, missing, and each of the 9 parents would be represented by at least three of the five tester matings (see table 5). Therefore, we decided to show and analyze all of the test results according to this incomplete, 5 × 9 factorial cross (as in tables 5-10).

We also decided to present results on foliar and bark resistance only after the blister rust disease had mostly run its course on the test progenies. With the 1952 progeny test, fairly conclusive results could have been obtained 4 years after the effective 1953 artificial inoculation. However, another, even more conclusive examination had been made in 1966; therefore, the results on tables 5-12 are given as of that year.

Variation in Percent of Rust-Free Seedlings

In time, rust from the artificial inoculation and the continuing natural inoculations almost blanketed the progeny test seedlings (tables 5 and 6). Even so, most the the more lightly infected parental lines noted in table 3 (17, 21, 24, and 37) remained the least infected through 1966, although by then percentages of rust-free seedlings had become very small. And the more heavily infected parental lines of table 3 (16, 20, 22, 30, and 39) approached 100 percent infection by 1966.

Thus, while in some families of table 5 there seemed to be a basis for complete freedom from rust, we were unable to substantiate such a belief. In fact, the proportions of seedlings exhibiting this character were so small that we hesitated to regard the rust-free seedlings as other than chance "escapes" from infection.

The passage of time also allowed us to further explore the perplexingly low susceptibility of wind-pollinated and ordinary nursery control seedlings that had been recorded one year after artifical inoculation (tables 3 and 4). Our expectation was that these apparently low susceptibilities would disappear with time, as indeed they did (table 6). At the bottom, right corner of table 6 are two sets of four percentages of infection that speak to this point. Note that through 1966 percentages of infection in the average wind-pollinated and control progenies caught up with or surpassed those in the average control-pollinated progeny, the control progenies by then being the most susceptible (98.6 percent infected). Progress of the rust epidemic as it blanketed the control-pollinated progenies is shown for individual progenies of the 5 × 9 factorial mating in the body of table 6.

Table 5.—Percent of infection with increasing progeny age (or by date of inspection) in an incomplete 5 x 9 factorial mating from the 1952 progeny test, through 1966[1]

Other parent	Tester parent 19				20				25				30				58				Family averages			
	1954	1955	1957	1966	1954	1955	1957	1966	1954	1955	1957	1966	1954	1955	1957	1966	1954	1955	1957	1966	1954	1955	1957	1966
1	76	84	94	95	80	84	94	98					78	90	93	94					78.0	86.0	93.7	95.7
16	74	90	94	98	79	85	98	99	90	94	96	98	72	91	97	97	84	88	98	99	79.8	89.6	96.6	98.2
17	81	91	96	96					74	86	92	94	71	87	94	94	72	86	91	91	74.5	87.5	93.2	93.8
18	78	90	97	97					74	91	97	98	73	92	99	99	72	84	94	94	74.2	89.2	96.8	97.0
21	39	73	93	93					60	82	97	99	66	84	96	100	56	79	93	94	55.2	79.5	94.8	96.5
22	73	84	94	96	89	93	99	99	84	96	98	100	77	90	96	97	82	91	96	97	81.0	90.8	96.6	97.8
24	78	95	100	100[2]	54	80	90	92									60	78	86	90	64.0	84.3	92.0	94.0
37	35	54	81	81[2]					75	75	79	79[2]	80	91	94	99	67	82	91	95	64.2	75.5	86.2	88.5
39	89	92	94	95	84	93	99	99					83	87	96	98	64	78	86	91	80.0	87.5	93.8	95.8
Family averages	69.2	83.7	93.7	94.6	77.2	87.0	96.0	97.4	76.2	87.3	93.2	94.7	75.0	89.0	95.6	97.2	69.6	83.3	91.9	93.9	73.4	86.1	94.1	95.6
Averages of wind-pollinated progenies[3]																					64.7	80.9	88.4	95.2
Averages of 5 control progenies																					59.6	79.9	93.1	98.6

[1]Unless noted under footnote 2, below, the test progenies averaged 81 seedlings distributed across all 9 randomized blocks.
[2]In all four years, based on a total of from 14 to 41 seedlings represented in 2 to 6 of the 9 randomized blocks.
[3]These averages are based on 12 of the 14 parents in the 5 x 9 factorial.

Table 6.—Percentage of completely rust-free seedlings in the test progenies of an incomplete 5 x 9 factorial mating from the 1952 progeny test, through 1966[1]

Other parent	Tester parent 19	20	25	30	58	Family averages
1	5.1	3.5		3.4		4.0
16	2.3	1.2	2.3	3.4	1.1	2.1
17	5.9		6.9	5.7	7.8	6.6
18	3.4		2.3	1.1	5.0	3.1
21	6.8		1.1	1.1	5.6	3.6
22	4.4	0	0	3.3	3.4	2.2
24	2.4[2]	7.7			7.9	6.0
37	19.2[2]		21.4[2]	1.3	5.7	11.9
39	4.6	1.3		2.1	9.1	4.3
Family averages	6.0	2.7	5.7	2.7	5.8	Grand average 4.6

[1]Unless noted under footnote 2, below, the test progenies averaged 81 seedlings distributed across all 9 randomized blocks
[2]Based on a total of from 14 to 41 seedlings represented in 2 to 6 of the 9 randomized blocks

Genetic Variation in Needle Lesion Frequency

The data on needle-spot frequencies arrayed for the same 5 × 9 factorial cross (table 7) proved to be more encouraging. Again, they followed the trends already outlined for table 4, but the differences between parental lines (families) were great enough and performance of progenies within parental lines consistent enough so that the genetic implications were clear. Thus, families of parents such as selection numbers 17, 19, 21, and 58, and possibly 24 and 37, contained progenies consistently below the grand average progeny in numbers of needle spots per 450 needles. Conversely, families of parents such as selection numbers 16, 20, 22, 30, and 39 contained progenies consistently above the grand average in numbers of needle spots. Presence of general combining ability (GCA) both for low and high needle spot frequency was obvious. Furthermore, prog-

Table 7.—Number of blister rust needle spots found on a sample of 450 secondary needles in the test progenies of an incomplete 5 x 9 factorial mating from the 1952 progeny test[1]

Other parent	Tester parent 19	20	25	30	58	Family averages
1	116	163		173		150.7
16	178	277	239	217	232	228.6
17	178		132	216	53	144.8
18	173		148	209	77	151.9
21	37		101	137	77	88.0
22	163	350	233	262	154	232.4
24	101[2]	176			148	141.7
37	113[2]		131[2]	205	133	145.5
39	190	251		359	269	267.3
Family averages	138.8	243.4	164.0	222.2	142.9	Grand average 177.0

[1]Unless noted under footnote 2, below, the test progenies averaged 81 seedlings distributed across all 9 randomized blocks.
[2]Based on a total of from 14 to 41 seedlings represented in 2 to 6 of the 9 randomized blocks

enies from matings between parents both of which produced characteristically lightly spotted lines, or heavily spotted lines, demonstrated the decided additivity present in the resistance: susceptibility systems. The inference could be drawn that identical resistance (or susceptibility) genes were present in several of the parental selections.

These were heady conclusions for us, and they delighted our cooperators and steering committee[8] members as well. We would have been even more delighted had we realized at the time that low needle lesion frequency probably was a uniform or horizontal resistance factor that might, characteristically, be more stable.

Genetic Variation Expressed by the "Spots-Only Syndrome"

Within a year our spirits received another boost as we began accumulating evidence of another form of foliar resistance. By 1955, it was becoming apparent that certain test seedlings that had borne blister rust needle spots thereafter failed to develop either suspect bark reactions or definite blister rust bark cankers. This phenomenon, outlined in table 8, soon became known as the "spots-only syndrome." In certain families of progenies (notably those of parents 17, 19, 20, 22, 24, and 58) average percentages of seedlings surviving rust attack due to the spots-only syndrome ranged up to 11 percent. Individual progenies in these lines ranged up to almost 17 percent survival due to the spots-only syndrome, while the grand average progeny had about 6 percent of its seedlings surviving. Again, GCA and additivity were strong features of the genetic system.

Table 8.—Percentages of progeny seedlings in the incomplete 5 x 9 factorial cross that had blister rust needle lesions but thereafter developed no bark reactions or cankers and thus survived, 1952 progeny test, through 1966[1,3]

Other parent	Tester parent 19	20	25	30	58	Family averages
1	9.3	2.4		2.3		4.7
16	4.6	4.7	0.0	1.8	3.5	2.9
17	11.2		6.2	9.8	16.9	11.0
18	1.2		1.2	7.9	1.2	2.9
21	9.1		1.1	1.1	2.3	3.4
22	11.6	11.4	6.7	2.3	11.6	8.7
24	5.0[2]	13.9			13.4	10.8
37	4.0[2]		9.1[2]	.0	4.8	4.5
39	8.4	1.4		2.2	1.2	3.3
Family averages	7.2	6.8	4.0	3.4	6.9	Grand average 5.7

[1]Unless noted under footnote 2, below, the test progenies averaged 81 seedlings distributed across all 9 randomized blocks
[2]Based on a total of from 14 to 41 seedlings represented in 2 to 6 of the 9 randomized blocks
[3]Percentages were computed after having reduced the numbers of seedlings tested in the various test progenies by the numbers of rust free seedlings (the seedlings of table 6).

[8]See appendix for anecdote.

Genetic Variation in Bark Resistance

We had been alerted to expect resistance reactions seated in the host bark by Riker and others (1949, 1953) and by Struckmeyer and Riker (1951), workers who reported the "corking-out" of established blister rust bark cankers in *P. strobus*. Sure enough, by 1955 to 1957 we began seeing various bark resistance reactions in our *P. monticola* test seedlings. With *P. monticola*, however, the host seedling's elimination of established infection took several forms. These included:

1. Rapid death and collapse of the infected bark tissues in the area of a young canker centered on the base of a needle bundle, usually under 0.25 inch (0.65 cm) diameter (fig. 10).

Figure 10.—These areas of previously infected bark centered about needle bundle bases collapsed and died so rapidly that we often missed the typical, orange bark discoloration associated with blister rust cankers.

2. Death and collapse of infected bark tissue but only as a ring around a canker situated as in (1) above.
3. More extensive bark reactions, most often centered about a needle bundle base with the disturbed bark tissue originally supporting rust mycelium, but the reaction area never assuming the orange-discolored, spindle-shaped canker symptoms typical of normal bark infections, nor later supporting the normal pycnial and aceial signs of the rust, usually 0.50 to 1.0 inch (1.3 to 2.5 cm) in length (fig. 11).
4. Still larger and rougher surfaced bark reactions that once had shown typical symptoms of the disease or signs of the rust fungus, but where the infected bark of the canker had been walled in by marginal wound phellogens—that is, "corked-out" in the Struckmeyer and Riker (1951) sense (fig 12).

Figure 11.—This bark reaction never showed the typical, outward symptoms or signs of the blister rust disease. It remained under 1 inch (2.5 cm) in length and eventually disappeared.

Figure 12.—This bark reaction once showed the typical orange discoloration of an active blister rust bark canker. Later the infected area of bark was sealed off and died inside rings of wound phellogens.

However, we could discern no patterns of parental performance in respect to seedling survival associated with these four kinds of bark resistance reaction, so we lumped all survival associated with the reactions in table 9. These were the most encouraging results we had seen emerge. Six of the 36 test progenies of the incomplete 9 × 5 factorial cross contained 20 percent to 30 percent of seedlings that survived rust attack, apparently due to their bark resistance. The parental lines 17, 19, 22, 24, and 58 were outstanding in bark resistance, the family average progenies containing from almost 4 percent to 12 percent more seedling survivors than did the grand mean progeny. Again, GCA, SCA, and additivity appeared to be features of the resistance system.

Table 9.—Percent of progeny seedlings in the incomplete 5 × 9 factorial cross surviving due to bark resistance reactions 1952 progeny test, through 1966[1,3]

Other parent	Tester parent 19	20	25	30	58	Family averages
1	12.1	1.2		2.4		5.2
16	2.4	2.5	0 0	.0	6.0	2.2
17	30.4		15.0	14.4	24.7	21.2
18	12.1		1.2	3.5	3.6	5.1
21	20.2		1.1	3.5	8.6	8.4
22	22.6	30.5	3.6	5.9	22.9	17.1
24	13.4[2]	8.2			27.2	16 3
37	10.3[2]		.0[2]	3.9	9.0	5.8
39	13.9	.0		2.2	6.3	5.6
Family averages	15.3	8 5	3 5	4.5	13.5	Grand average 9 6

[1]Unless noted under footnote 2, below, the test progenies averaged 81 seedlings distributed across all 9 randomized blocks

[2]Based on a total of from 14 to 41 seedlings represented in 2 to 6 of the 9 randomized blocks.

[3]Percentages of surviving seedlings were computed removing seedlings that had survived because they never became infected (as in table 6), or because of the spots-only syndrome (as in table 8)

Genetic Variation in Seedling Survival

Finally by 1957, 4 years after artificial inoculation at seedling age 6 years, we were ready to estimate the total percentages of progeny seedlings that survived rust exposure or attack. This figure, after all, was the most important in respect to the practical utility of the tested, first-generation stocks. As with tables 5 to 9, 1966 results are given here, but they had changed little since 1957. These total percentages of survival due to all resistance factors are given in table 10. Individual progenies contained from less than 2.5 percent to more than 41 percent surviving seedlings, with the grand average progeny containing almost 18 percent of survivors, or 14 percent more survivors than the controls—encouraging numbers. Five of the 14 parents (5 testers and 9 other parents) tested in the incomplete factorial cross (numbers 17, 19, 22, 24, and 58) seemed to be exhibiting good GCA for resistance. Their average progenies ranged from about 5 percent to 15 percent higher in seedling survival than the factorial's grand mean progeny (with 17.9 percent survival).

Table 10.—Percent of progeny seedlings surviving due to all kinds of resistance reactions of the host foliage and bark in an incomplete 5 × 9 factorial cross, 1952 progeny test, through 1966[1,3]

Other parent	Tester parent: 19	20	25	30	58	Family averages
1	24.1	7.1		7.8		13.0
16	9.1	8.1	2.3	5.1	10.2	7.0
17	40.0		25.2	26.3	41.2	33.2
18	15.7		4.5	12.2	10.0	10.6
21	32.2		3.3	5.6	15.5	14.2
22	26.7	36.4	10.0	18.6	33.6	25.1
24	19.5[2]	26.9			40.5	29.0
37	30.6[2]		28.5[2]	5.2	18.1	20.6
39	20.6	2.6		6.3	15.9	11.4
Family averages	24.3	16.2	12.3	10.9	23.1	Grand average 17.9
				Average of 5 controls		4.1

[1]Unless noted under footnote 2, below, the test progenies averaged 81 seedlings distributed across all 9 randomized blocks.
[2]Based on a total of from 14 to 41 seedlings represented in 2 to 6 of the 9 randomized blocks
[3]Percentages were computed using total number of surviving seedlings over the total number of seedlings tested—that is, there were no progressive reductions in the numbers of test seedlings as in tables 8 and 9

Table 11.—Percentage of seedlings surviving in test progenies of parents exhibiting general combining ability for resistance, 1952 progeny test, through 1966[1]

Male parent	Female parent: 17	19	22	24	58	
17		40.0	38.6		41.2	
19	(40.0)		(26.7)	(19.5)[2]	(24.4)	
22	(38.6)	26.7			33.6	
24		19.5[2]			40.5	
58	(41.2)	24.4	(33.6)	(40.5)		
Family averages	39.9	27.6	33.0	30.0	34.9	Grand average 33.1
				Average of 5 controls		4.1

[1]Test progenies contained on the average of 81 seedlings distributed across all 9 randomized blocks; the number of progenies is artificially doubled by entering values for the reciprocal crosses, in parentheses.
[2]Based on only 41 seedlings in 6 of the 9 randomized blocks.

Table 12.—Infection and survival of test seedlings in 6 self-pollinated progenies, 1952 progeny test, through 1966

Parent	Number seedlings tested	Percent of seedlings infected: 1954	1955	1957	1966	No. spots per 450 needles, in 1954	Percent survival by resistance-reaction categories: Never infected	Needle spots only[1]	Bark reactions[1]	Total
19	90	73	90	96	96	128	4	7	30	38
20	8[2]	38	50	62	62	50	38	--	—	38
22	26[2]	54	79	83	90	333	10	18	29	47
30	18[2]	56	83	89	94	510	6	7	7	19
39	65	68	78	83	95	247	5	2	10	17
58	90	81	86	93	96	152	4	9	32	42

[1]Percentages were computed removing surviving seedlings from previous 1 or 2 columns from total numbers of seedlings tested.
[2]Represented by only 8 to 26 seedlings in only 2 to 4 of the 9 randomized blocks, otherwise by an average of 82 seedlings in all randomized blocks

Level of Survival in "GCA-F_1" and S_1 Progenies

An outstanding and encouraging result was the survival in progenies of parents that both expressed GCA for resistance. Inadvertently we had produced eight such GCA-F_1 progenies from crosses among the five GCA trees, (parents such as numbers 17, 19, 22, 24, and 58). We found a 33.1 percent average level of surviving seedlings in the eight progenies. This was almost 30 percent higher than in the control progenies (table 11).

There were five GCA trees found in the 5 × 9 factorial cross, or over one-third of the 14 trees involved. However, a perusal of the rest of the 1952 progeny test data (including 62 more control-pollinated plus 16 wind-pollinated progenies) showed that the proportion of GCA trees was probably nearer to 1 out of 4 rust-free trees.

Also from the 1952 progeny test came information on the resistance of S_1 (self-pollinated) progenies (table 12). Here, performance of the larger and more reliable progenies followed that of the cross-pollinated progenies discussed above. There were small increments of resistance coming from several foliar and bark resistance factors, together accumulating to the point where about 20 to 40 percent of the self-pollinated seedlings survived intense exposure to the rust.

OTHER RESEARCH ON *PINUS MONTICOLA*

The BEPQ Office of Blister Rust Control and the author had been assigned the foregoing research, or developmental work, on blister rust resistance. Meanwhile, Tony Squillace of the Northern Rocky Mountain (now Intermountain) Forest and Range Experiment Station had been conducting a less well-staffed and financed program investigating *P. monticola* variation in respect to other qualities. In practice, Tony and I worked closely and published together on both phases of the work.

By 1954, we had produced evidence of significant correlation between height growth of *P. monticola* parents and F_1 progenies 85 ($r = 0.30$ to 0.80) (Squillace and Bingham 1954). Shortly thereafter we had detected and reported what appeared to be localized, site-associated, ecotypic variation, as well as elevation-associated variation in *P. monticola* height growth and seed germination (Squillace and Bingham 1958a). We had found and reported for self-pollinated *P. monticola* a 50 percent reduction in filled seed yield per cone, a 7 to 13 percent reduction in seed germinability, and an 11 to 21 percent reduction in early height growth (Bingham and Squillace 1955). We also described some of the phenological features of 'flowering'' in the species (Bingham and Squillace 1957). Also, Squillace had investigated within-tree variation in cone characters, seed yield, and seed weight of *P. monticola* (Squillace 1957), and he had installed a number of flower induction studies with the species. Lastly, we had assembled a great deal of raw data on cone and seed yields of young *P. monticola* trees.

Thus, by 1957 we had learned a little about the genetics of *P. monticola* aside from blister rust resistance, as well as a fair amount concerning the species' reproductive biology. Nevertheless, we needed to know a great deal more concerning (1) ecotypic and altitudinal variation as affecting plantings of improved *P. monticola* strains, and (2) seed orchard management for the species.

1957 — OUR YEAR OF DECISION

By late summer 1957, the positive and encouraging results on transmission and extent of blister rust resistance in the F_1 progenies of the 1952 progeny test had become so firm, and newer results from the 1953 to 1955 progeny tests so supportive, that we researchers could draw some fairly safe, if broad, conclusions concerning the nature, extent, and utility of blister rust resistance in Inland Empire *P. monticola*. Those conclusions were:

1. The apparent blister rust resistance that had been isolated by natural selection in rare, rust-free *P. monticola* trees in rust-decimated natural stands was indeed real, and it was under strong genetic control.

2. Crosses among the rust-free parent selections had produced F_1 progenies, and performance of these progenies showed that in all probability there were several, to many, resistance-genes in the overall resistance system. Effects of these genes were visible as a succession of host resistance reactions that occurred over 3 or more years as the rust spread first to foliage and later to bark.

3. Apparently many of the same resistance-genes occurred in the genotypes of different rust-free parental selections, for many of the same or similar resistance reactions occurred in F_1 progenies representing different parental selections.

4. There was little evidence that single, major (dominant or recessive) genes were present in the resistance system; rather, a seemingly classic picture of quantitative inheritance of resistance had emerged. Instead of the 25, 50, or 100 percent increments of resistance expected in progenies under single major-gene-controlled inheritance, we experienced much smaller increments associated with each resistance reaction. Polygenic inheritance, incomplete dominance, or some other form of inheritance of resistance was suggested.

5. Both general combining ability (GCA) and specific combining ability (SCA) were found in the resistance system, with GCA being a prominent feature. About one-fourth of the rust-free parents produced parental lines of F_1 progenies wherein most, or all, of several progenies were above average in resistance (that is, the parents exhibited GCA for resistance). And when these GCA parents were perchance mated, they produced noteworthy GCA-F_1 progenies in which an average of about 30 percent more of the F_1 seedlings survived intense, artificial and natural exposure to the rust than did control seedlings.

Thus, in 1957 we researchers and our administrators were faced with our first major policy and financial decision on whether, and how, to go ahead toward mass production of blister rust resistant planting stock. Based on the results and conclusions outlined here, the decision to go ahead was immediate and unanimous. But we reserved for further study detailed and technical questions such as: (1) level of resistance required for practical planting, (2) time available to secure that level of resistance, (3) stratigies we might be able to incorporate in the program as ''insurance'' against new or different pathogenic rust races, (4) new research facilities that would be needed, and (5) the funding and staff required to do the job.

The question of any new laboratory, greenhouse, nursery, and other facilities was not one we were allowed to ponder long. A chance, early fall 1957 visit by Forest Service Washington Office inspectors—happily coming at a time and place almost ideal for demonstrating extent of resistance—led within 2 weeks to construction funds for a research facility and tacit approval for increased R&D budgets and staff.[9] Planning and bid letting for the facility were completed by spring 1958, and construction was completed by that fall.

1958 to 1959 — A PLANNING AND TRANSITION PERIOD

We spent most of 1958 and 1959 winding up the four preliminary progeny tests, planning and establishing a new resistance research facility, and deciding the directions and priorities of new R&D work.

Decisions on directions and priorities were handled with the help of a Steering Committee for Blister Rust Resistance Research.[8] Together we made sometimes arbitrary assumptions and decisions just to get on with the work. Those assumptions and decisions were:

[8] See appendix for anecdote.

[9] See appendix for anecdote.

1. With the funds, staff, and time available, we wanted to secure plantable resistant stocks well before the year 2000. If this time limit could not be met, a reappraisal of the entire R&D program would be undertaken.

2. Some level of resistance substantially above the 30 percent survival observed for GCA-F_1 progenies under intense artificial inoculation would be necessary before resistant nursery stock could be considered plantable. Within the time limits of (1) above, this arbitrary decision meant: (a) use of GCA-F_1 stock, if 15 to 25-year tests showed the field level of resistance to be well above 30 percent survival; or (b) use of F_2 stocks bred from resistant F_1 seedlings, if level of survival under artificial inoculation was well above 30 percent.

3. To provide some genetic breadth against pathogenic variation in *C. ribicola*, as well as against inbreeding depression of growth in seed orchard stocks, we would have to substantially broaden the genetic base of rust-free parents entered in the program. Considering the money, staff, and time available, a 400-tree base would seem to be a realistic goal.

4. Primary selection would be for GCA for resistance. Thus, with only one in four parents embodying GCA, the 400-tree base would be reduced by selection to about 100 GCA trees. Then, to prevent maladaptation of planting stock, the 100-GCA-tree base probably would have to be further subdivided among elevational-zone orchards. This would reduce the base to an extent precluding improvement of any trait other than blister rust resistance.

5. There were about 2 million acres of potential white pine lands in the Inland Empire, roughly half of which fell in the better white pine site indexes. In these better lands, clearcutting and wildfire together could be expected to provide only about 10,000 to 20,000 acres per year for planting. Planting would be restricted to the better white pine lands with a spacing after rust losses not to exceed 15 ft by 15 ft (4.5 m by 4.5 m), or about 200 trees per acre (about 500 per ha).

Finally, before embarking on a R&D program at the new Genetics Center, we scientists added a few observations and recommendations of our own, mainly concerning improved technology for progeny testing. These recommendations were:

1. Use of a single, heavy, artificial inoculation at rust-sensitive seedling age 2 years had proved to be highly efficient for rapid and thorough progeny testing. We would continue this practice for future F_1 and F_2 progeny testing, meanwhile attempting to control extraneous variations introduced by inoculum quality or by variability in microclimates inside, or weather outside, inoculation tents.

2. Tony Squillace's 9-block experimental design had served well in the preliminary progeny testing, but had two failings. First, there were many seedlings lost from nongermination, damping off, and so forth, resulting in the number of seedlings in row-plots being substantially reduced; the binomial (percentage) data for row plots then became quite shaky. Second, the single row-plot per block provided no means for estimating within-block variance. We decided to increase the number of seedlings within a row-plot to 16, but balked at having two or more row-plots per block because of the consequent doubling of all operations and costs.

3. Continued reliance on controlled pollination would be safest for the near future. Meanwhile, we should experiment with various means for reducing pollination costs, first by using mixed-pollen crosses, and second by testing larger wind-pollinated progenies, possibly coming from mixtures of seed from 2 or more seed years.

4. Future R&D work undoubtedly would be more efficient and economical under some factorial or partial diallel crossing scheme. We decided that for future work of determining new GCA trees to use a factorial cross, each new and untested, rust-free parent being mated with four tester parents. This way we should be able to test many more parents than in the past for equal outlays in staff time and funds, and results between parents would be comparable, each new parent being represented by an equal number of test progenies including identical tester germ plasm.

5. We were expecting to encounter both elevation-associated variations (which we could handle in seed orchards as described above), as well as localized ecotypic variation (which with our 400-tree base we would be forced to ignore). Critical, long-range experiments were needed to confirm the extent of such variation and to prescribe the composition of seed orchards to handle the variation.

6. Inbreeding and associated depression of height growth, seed yield, and so forth was expected in *P. monticola* seed orchards. Critical experiments were needed to verify degree of inbreeding depression and to define possibly offsetting effects of selective fertilization. Orchard inbreeding coefficients should be calculated considering any selective fertilization effects.

7. Applied research was needed on *P. monticola* cone and seed yields, flower induction, vegetative propagation, and exploring other features of seed orchard technology.

8. In view of the high costs of empirical progeny testing, indirect selection for resistance—particularly seeking chemical and anatomical markers—should be explored.

The above assumptions, arbitrary decisions, and research recommendations shaped the new R&D program that followed. The preliminary research period indeed had been interesting and profitable.

A NEW R&D PROGRAM FOR THE 1960'S AND 1970'S

In 1954, the forest disease and insect control functions of the Bureau of Entomology, and similar research functions of the Bureau of Plant Industry, Soils, and Agricultural Engineering, were all finally blanketed into the Forest Service. This ended the crazy-quilt administration of forest pest control research. The Spokane Office of Blister Rust Control, BEPQ, then moved as a unit under a new Division of Blister Rust Control, Forest Service, Region 1, Missoula. This new division for a time retained control of all work of the D&I subunit. Financially, this probably was good because blister rust control work still was more amply funded than Forest Service research under the Experiment Station. Gradually, however, funding for new research in the Intermountain Station was increased to the point where in 1960 the Station took over administration of resistance research. By agreement, however, the Division of Blister Rust Control, and later the Division of State and Private Forestry of the Region, continued to finance any developmental work. This split the resistance R&D budget about 50–50 between the two agencies.

One of the bitterest pills I had to swallow as a member of the Forest Experiment Station was the decree that each research project would have detailed written problem analyses and study plans. Fortunately for me as a new research project leader, my immediate supervisor, Charles A. (Chuck) Wellner, chief of the Intermountain Station's Division of Forest Disease and Timber Management Research, was a close personal friend and a forest

researcher and research administrator of outstanding stature. Wellner was able alternatively to smooth my ruffled feathers and curb my tendencies toward empire-building. And, from 1960 to 1964, a detailed problem analysis and 17 study plans were prepared.

The problem analysis broke the overall research job into three major problem areas each with two to three phases, then cited specific studies aimed at solving the various phases. The major research problems and phases were:

I. Provision of resistant planting stock
  A. Early generation breeding
  B. Advanced generation breeding
  C. Seed orchard technology
  D. Supporting studies on inbreeding, elevational variation, and ecotypic variation

II. Increasing efficiency of selection
  A. Reducing time and cost of pollination work and progeny testing
  B. Indirect selection for anatomical and biochemical markers

III. Physiologic races of the rust
  A. Stockpiling additional resistance genes
  B. Genetics of the host:pathogen couplet
  C. Incorporating resistance genes from Eurasian white pines

Beyond this research program would be the developmental work of expanding the genetic base to 400 rust-free selections and about 100 GCA trees; also of any planning, preparing, and establishing the first phase seed orchards for mass production of resistant seed.

However, to illustrate the R&D program's balance of fundamental and applied research versus developmental work, the individual studies of the problem analysis are detailed below. Major Problem Areas (I,II,III) and Phases of the Areas (A,B,C,D), as covered above, are identified and study priorities are given. This is followed by a discussion of results that bore on the production of first-phase resistant planting stock.

Fundamental Research

QUANTITATIVE GENETICAL METHODS

I, B—highest priority: estimating first- to second-generation gain in resistance using quantitative genetical methods.

The steering committee and we scientists had decided that resistance substantially above 30 percent survival would be required to render planting stocks technologically or economically plantable. We also recognized that within our time frame, the increased resistance would have to come from one of two sources: (1) from substantially increased resistance of GCA-F_1 progenies in the field where subjected only to natural inoculation, presumably of much lower intensity but of much longer duration; or (2) from GCA-F_2 progenies that exhibited a substantial F_1 to F_2 gain in resistance under artificial inoculation. In either case, empirical determination of resistance seemed to be a 10- to 25-year proposition. Therefore, we decided to give first priority an attempt to **estimate** first- to second-generation gain in resistance from resistance data already in hand.

In the late 1950's, such heritability and genetic-gain analyses were new outgrowths in quantitative genetics (Lush 1956; Kempthorne 1957) and, except for the work of Toda (1958) and Toda and others (1959), were almost unknown in forest trees. Nevertheless, propelled by our urgent research needs, from 1957 to 1959 Tony Squillace and I plunged into the work of estimating second-generation gains in resistance under continued selection for GCA. Basic data for these analyses were percentages of survival determined for progenies of the 1952 test.

The review draft of the proposed research paper coming from this work was sent to frequent visitor and old friend Dr. Jonathan W. Wright, geneticist with the Department of Forestry of Michigan State University. It was returned so spattered with succinct commentary and so much improved by Wright's (then, to us, very sophisticated) suggestions for improved heritability analyses that we soon induced him to accept co-authorship of the paper. After review by a few quantitative geneticists, this first of our heritability and gain papers was published (Bingham and others 1960). Narrow-sense heritability was estimated as 0.688—an encouragingly high figure. We used the 30 percent gain in survival of GCA-F_1 progenies over the controls as the selection differential in the case of selection for GCA. The result was a genetic gain accruing to the second cycle of selection of $0.688 \times 0.30 = 0.21$, or 21 percent. Thus, combining first-(30 percent) and second-generation (21 percent) gains, it was estimated that second-generation GCA-F_2 progenies would contain about 51 percent seedlings capable of withstanding intense artificial exposure to the rust.

The estimated 50+ percent survival was probably the single most important figure we were ever to develop in the 25-year, first-phase, R&D program. This was because we researchers, our cooperators, and our steering committee all accepted that level of survival as adequate to justify large-scale planting of blister rust resistant planting stock. **This decision, in effect, locked us into a program for mass-producing GCA-F_2 stocks.** Immediately we commenced the expensive, 10-year program of developmental work test crossing and progeny testing the 330 new rust-free parents needed to bring the overall genetic base up to 400 trees and the base in GCA parents up to about 100 trees.

Less than a year later we were questioning the validity of some of our 1960 heritability analyses and recalculating first- to second- generation gain as perhaps only 10 percent. In spite of this, our cooperators and steering committee continued to give us the green light toward mass-production of the presumably 40 to 50 percent resistant GCA-F_2 planting stock. We made two later attempts to reestimate genetic gain (Bingham and others 1969; Becker and Marsden 1972). Based on four different progeny tests, estimated gains ran between 10 and 30 percent, estimated survival in the GCA-F_2's between 21 and 59 percent. Still later we found that the assumption of purely quantitative, polygenic inheritance of resistance probably was in error. Fortunately, by then we had highly encouraging empirical tests of resistance levels in GCA-F_2's, the results of which were available before we began installation of seed orchards. In other words, we "lucked out" on the matter of genetic gain; we might well have been producing F_2 planting stocks with a survival level under artificial inoculation that fell well below the acceptable but hypothetical 40 to 50 percent.

SEEKING CHEMICAL MARKERS

II, B—moderate priority: seeking chemical markers for possible use in indirect selection.

With costs for test crossing and progeny testing running at $1,000 to $2,000 per rust-free selection, we felt justified, even obligated, to investigate possible chemical and anatomical

markers for resistance; indirect selection using such markers well might reduce the high costs of selection.

In the fall 1958 Dr. James W. Hanover joined the Genetics Center in a new position specifically for investigating the chemistry of resistance. Over the next few years, Jim studied the relation of inorganic chemicals such as amino acids, organic acids, sugars, phenolics, and terpenes, to blister rust resistance in *P. monticola* (Hanover 1963a, b; 1966d; Hanover and Hoff 1966). This work was continued until 1969 by Dr. Raymond J. Hoff, who in 1964 assisted and then replaced Jim Hanover. Ray Hoff concentrated on a few of the more promising leads developed by him and Jim Hanover, notably with phenolics (Hanover and Hoff 1966; Hoff 1968; Hoff 1970) and with dry weight, where assisted by visiting German scientist Dr. Peter Schütt, (Schütt and Hoff 1969).

In the end, however, none of the potentially useful chemical markers proved consistently to be diagnostic of blister rust resistance. Nevertheless, we gained an extensive biochemical profile of *P. monticola* and, in time, some of the first knowledge on gene control of terpenes in *Pinus* (developed by Jim Hanover, later, while at Michigan State University; see Hanover 1966a, b, and c; and 1971). This was probably not too little to ask for our more than 5 scientist-man-years of work, especially considering the naivete of our approach. In retrospect, we realize the lack of success is not suprising now that we know just how few cells are involved in certain resistance reactions, or that we lacked genetic control, or even knowledge of some of the array of resistance genes.

THE PATHOGENICITY SYSTEMS

III, B—moderately high priority: genetics of the host: pathogen couplet.

By the mid-1960's, after failing to identify any chemical markers to resistance, we were ready to undertake new lines of research. We chose to study the genetics of the *P. monticola:C. ribicola* (host:pathogen) couplet because knowledge of the resistance and pathogenicity systems would be important for securing more stable resistance and because a wealth of new study materials was available.

In the process of developmental work increasing the program's genetic base from 70 up to 400 selections, over 300 new, rust-free, wild-stand selections were under test. Each new selection was represented by up to 160 seedlings in each of four test cross progenies, and at times (across several years of progeny tests) over 100,000 artificially inoculated seedlings were under test at one time. When rust examinations were to be made in the progeny test, we never seemed to have enough personnel, so all scientists, technicians, even secretaries, were blanketed into the inspection crews. This included Dr. Ray Hoff, and newly employed (1966) Dr. Geral I. McDonald. These two somehow managed to keep their heads above the waters of established examination routine far enough to make some astute observations on the host:pathogen couplet.

Ray Hoff and Geral McDonald first focused on the long-recognized but still unexplained needle-spots-only syndrome. Soon they established that the syndrome was a two-step resistance reaction: the first increment of resistance coming from premature shedding of infected needles, the second from the failure of the rust mycelium associated with certain remaining foliar infections to extend through the needle and short shoot (fascicle base) into the seedling's bark (McDonald and Hoff 1970). Then Ray Hoff pointed out the anatomical basis for the second increment of resistance, showing that the death of host cortical cells and of associated rust hyphae was occurring in and just distal of the host's short shoots (Hoff and McDonald 1971). Finally, the two scientists developed a statistically tenable genetic hypothesis accounting for the two resistance reactions and increments of resistance as found in the complete spots-only syndrome (McDonald and Hoff 1971). The hypothesis proposed a first recessive gene controlling premature shedding of infected needles, followed by a second recessive gene controlling failure of still established needle infections to spread through the short shoot and into the bark. This hypothesis remains unverified by other workers or with other materials; however, the materials Hoff and McDonald tested came from five different progeny tests, and in that sense the verification was repetitive.[10]

We never were able to develop a good explanation for the difference in the conclusions of quantitative (not major-gene) inheritance of resistance that Tony Squillace and I reached with the 1952 test versus that of major-gene inheritance that Hoff and McDonald reached. It seems highly unlikely that virulent races that had negated resistance of Hoff and McDonald's major-genes in the 1950's had since disappeared. One possible explanation is that the intensity of artificial inoculation somehow overrode the resistances found in the later tests; but this explanation also is unlikely because infection levels near 100 percent were reported by McDonald and Hoff (1970 and 1971). Still another explanation is that in the 1952 test effects of these major secondary foliage resistance genes were bypassed because the rust attacked via primary needles or directly via succulent bark tissues (Van Arsdel 1968), both as found on late-season lammas growth. This also seems unlikely because we have no records or recollection of much lammas growth with primary needles present, although we do have records of rare, infected primary foliage. Unfortunately, we ran out of large progeny tests and the opportunity to really verify the findings concerning these major resistance genes.

Evidence of other simply inherited forms of resistance was not long in coming. In spring of 1964, Ray Hoff and Geral McDonald observed and, using microscopic examination, verified that red as well as the common yellow needle spots were blister rust symptoms. Curiously, we had never noted such red spots, nor a reference or photo of them, prior to that time. But these red spots became a feature of every progeny test since undertaken. Within a few years, Ray Hoff and Geral McDonald had accumulated a large body of data on occurrence and frequency of the two colors of spots on a variety of test progenies. Thus, in time, proposing hypothetical genotypes for various parents, and checking these proposals via chi-square analyses of progenies, the two researchers were able to provide some of the first, fairly strong evidence for existence of pathogenic races in a forest tree rust (McDonald and Hoff 1975). The statistically tenable hypothesis involved one pathogenic race of the rust that produced yellow needle spot symptoms and faced off against a recessive resistance gene, and a second race that produced red needle spots and faced off against a dominant resistance gene; sort of a classic gene-for-gene system. This hypothesis also remains in need of confirmation. McDonald (1978) was unable to verify it after inoculating *P.*

[10]See appendix for anecdote.

monticola seedlings with sporidia from single spore aeciospore inoculated ribes leaves; the aeciospores came from clusters of aecia borne on single cankers on trees previously rated as red spotted only, red and yellow spotted, or yellow spotted only. However, this did not disprove the hypothesis because the mechanics of fertilization in *C. ribicola* remains to be clarified.

Ray Hoff and Geral McDonald (1972b) went on to summarize the several resistance reactions and hypotheses concerning their control by resistance genes as follows:

1. Resistance to yellow-spot-forming race (single recessive gene), to red-spot-forming race (single dominant gene), and, by inference, to both races (that is, no spots).
2. Reduced lesion frequency on secondary needles (single nondominant gene or gene(s) of uniform resistance type).
3. Premature shedding of infected needles (single recessive gene).
4. Fungicidal reaction in the vicinity of the short shoot (single recessive gene).
5. Rapid necrosis of bark surrounding infected needle bundle bases (sort of an overblown bark hypersensitivity reaction-genetic control unknown).
6. Corking-out of established bark cankers (extensive wound-periderm formation, genetic control unknown).
7. Slow canker growth (genetic control unknown but probably of uniform resistance type).

Ray Hoff and Geral McDonald pointed out that while most forms of resistance found probably were of the vertical (or differential) kind (single, major-gene-controlled, and thus requiring but a single mutation by the rust for negation), at least the reduced needle lesion frequency and slow canker growth forms of resistance appeared to be of the more stable horizontal (or uniform) or tolerance types. However, they also pointed out that certain vertical types of resistance, such as spots-only resistance, had persisted for long periods in species such as *Pinus griffithii* and *Pinus armandii* (Hoff and McDonald 1972a,b) from near the central Asian *C. ribicola* gene center.

Basically then, this was the resistance information available for planning the developmental work toward seed orchard production of first-phase resistant stock.

ELEVATIONAL AND ECOTYPIC VARIATION

I, D—high priority: effects of elevational and ecotypic variation.

The Inland Empire's natural stands of *P. monticola* in the U.S.A. extend across a scant 3° of latitude or longitude; thus, we were not anticipating much geographic variation in the species. The elevational range of the species, however, is more than 3,000 ft (915 m), so we were expecting some elevation-associated genetic variation. This proved to be the case. Our earliest results on height growth in *P. monticola* (Squillace and Bingham 1958a) showed high-elevation lots, from one 5,000 ft (1 525 m) area exhibiting slow growth at age 2 years in a low-elevation nursery, but fairly good growth on a 4,400 ft (1 340 m) outplanting plot at age 4 years. Furthermore, the same study indicated that *P. monticola* contained localized, site-associated variation. Thus it was that Dr. Burton V. Barnes (who replaced Tony Squillace in 1958) immediately commenced study of the elevational and other variations over the entire range of Inland Empire *P. monticola*. By 1967 Barnes had shown that in one long northern Idaho drainage, the **phenotypic** variation in periodic annual height growth differed significantly only at the highest elevations, over 4,600 ft (1 400 m) (Barnes 1967).

We recognized that this natural genetic variation was a possible stumbling block to securing adaptation of resistant planting stock. We also recognized that critical studies confirming the extent and importance of elevational and localized ecotypic variation, while of high priority, were long-range, and that we would still be awaiting answers when it came time for the first-phase orchards to be established. Thus, lacking firm answers, we merely set up low-, medium-, and high-elevational zones for all GCA trees and corresponding low-, mid-, or high-elevational seed orchards.

Unfortunately, seed orchards for the production of low-, mid-, and high-elevation, resistant F_2 stocks already had been established and growing for 5 years before we could obtain more definitive information on elevational and localized ecotypic variation. First Dr. Raphael J. (Ray) Steinhoff (who replaced Burt Barnes in 1965) interpreted results on tree growth for up to 16 years from 4 nursery tests and 13 field plantations. He showed conclusively the lack of elevationally associated variation in growth except in *P. monticola* materials from the highest elevations of over 4,500 ft (1 375 m) (Steinhoff 1979). Second, Dr. Gerald E. (Jerry) Rehfeldt (the project's "gene-ecologist" who arrived in 1967)—working with control-pollinated progenies from 3,100, 3,850, and 4,600 ft (950, 1 175, and 1 400 m) showed that Squillace and Bingham's (1958a) localized ecotypic variation probably was a myth—an artifact of the particular materials studied or of experimental error. Instead, Rehfeldt (1979) found little variation associated with aspect or elevation, except at the highest elevations. He also pointed out how such "phenotypic plasticity" could well represent an alternative adaptive strategy to the relatively complex patterns of populational differentiation we were finding in other Inland Empire conifers. Rehfeldt (1979) also cited other studies on height growth and terpenes of *P. monticola* that supported the "phenotypic plasticity" hypothesis for the species (Hunt and von Rudloff 1977; Townsend and others 1972).

Long-range payoffs from detection of this plasticity in Inland Empire *P. monticola* are self-evident. Seed from currently established low- and mid-elevation orchards can be lumped and planted over a much wider range of elevations than had been anticipated. Also, this plasticity will greatly simplify the structuring of future seed orchards, in effect increasing the genetic base of materials entering a given orchard (Hoff and McDonald 1980a).

SELFING AND SELECTIVE FERTILIZATION

I, C—moderate priority: effects of selfing and selective fertilization on *P. monticola*

Bingham and Squillace (1955) showed that under controlled self- pollination of *P. monticola*, the bulk of individual trees proved to be partially self-fertile, and that the selfing was accompanied by an almost 60 percent drop in number of seedlings produced and a more than 20 percent reduction in height growth of young seedlings. Soon we would be considering grafted seed orchards with many genetically identical ramets of each GCA tree ortet, or resistant F_1 seedling seed orchards, with many full sib seedlings of each GCA-F_1 progeny. It behooved us, then, to know more about effects of selfing in older trees, and about possibly offsetting effects of selective fertilization under wind-pollination of seed orchard trees.

By 1964 we knew that inbreeding depression of height growth in S_1 progenies persisted through age 10 years, and appeared to have increased to near the 30 to 40 percent level (Barnes 1964). But we also knew that there were strong selec-

tive fertilization effects favoring outcross pollens in mixes of self and outcross pollens. In fact, some completely self-fertile trees might be mostly outcrossed depending on the pollinators. And with certain partially self-fertile trees, outcross pollen might be as much as five times as effective as self pollen in effecting fertilization (Squillace and Bingham 1958b; Barnes, Bingham, and Squillace 1962).

On reflection, however, our concern about the effects of inbreeding in seed orchards was probably "much ado about nothing." The Sandpoint experimental grafted orchard (see "Seed Orchard Technology") was composed of 13 clones and had a potential inbreeding coefficient of 0.077; the final first-phase seedling orchards would be composed of 12 full-sib lines with a potential inbreeding coefficient of 0.010. Thus, if there were completely panmictic fertilizations in these two orchards and 35 percent inbreeding depression of height growth under full inbreeding, the corresponding depressions of height growth should amount to only about 2.7 percent in trees from Sandpoint and less than 0.5 percent in trees from first-phase orchards.

We worried even less about effects of inbreeding in our seed orchards when we added the following facts: (1) any inbreeding probably would be accompanied by a decrease in seedling yield; (2) outcross pollens probably would be favored in effecting fertilization; and (3) that ramets of the 13 Sandpoint ortets, or half-sibs of the 12 full-sib lines of the first-phase orchards, were or would be physically separated by using a spacing system such as that of Langner (1953).

Applied Research

F_1 TO F_2 GENETIC GAIN

I, B—high priority: empirical determination of F_1 to F_2 gain under artificial inoculation in the nursery.

After 1960–61, with the estimate of more than 10 to 20 percent gain in seedling survival between the F_1 and F_2 generations, and 40 to 50 percent or more survival in GCA-F_2 progenies (Bingham and others 1960, 1961), our developmental work program was almost locked onto F_2 seedling seed orchards. Thus, verification of the actual F_1 to F_2 genetic gain became a high priority study, especially because results would probably be available in time to forestall installation of seed orchards should the 1960 and 1961 estimates of gain prove to be unrealistically high.

Beginning in 1957, resistant GCA-F_1 seedlings from the preliminary 1952 to 1955 progeny tests were salvaged from field plots and accumulated in the fertile, sprinkler-irrigated, fertilized, and cultivated Moscow Breeding Arboretum. The oldest of these resistant F_1 seedlings had begun to produce female strobili by age 7 (in 1958) and male strobili by age 12 (in 1963). Significant production of female strobili occurred at age 10 (in 1961) and of male strobili at age 14 (in 1965). By 1967 we were able to enter a fair number (32) of F_2 progenies into the regular progeny tests used to determine new GCA trees.

The outcome of these tests involving F_2 progenies was far more encouraging than we had expected based on previous experimental estimations of genetic gain (from estimates of Bingham and others 1960, 1961, 1969, Becker and Marsden 1972). Instead of 50 percent or less of the GCA-F_2 seedlings surviving artificial inoculation, we found that more than 65 percent survived (Hoff and others 1973).

Apparently the increase over estimated percentage of survival was due to the involvement of major genes in the resistance system. However, we were unable to substantiate this hypothesis because certain F_1 parents we thought were homozygous recessive for one of the spots-only syndrome resistance genes, produced F_2 progenies with only 88 percent survival. Possible explanations for the less than 100 percent survival in some F_2 progenies were that infections had occurred via primary needles on lammas growth or persistent from the year previous to inoculation or directly via succulent bark (Van Arsdel 1968). However, in the latter case, after 20 years and more of progeny testing of more than 250,000 inoculated seedlings, such direct stem penetration has never been demonstrated here for *P. monticola*.

These findings, first known in late 1970, provided the final impetus for proceeding toward GCA-F_2 seedling seed orchards.

LEVELS OF FIELD RESISTANCE

I, A and B—high priority: empirical determination of levels of field resistance in F_1 and F_2 stocks.

Until 1970, as described for the foregoing study, we had only estimates of the level of resistance that would be attained in artificially inoculated F_2 stocks, and no knowledge that field resistance, even in F_1 stock, might not be great enough for practical use.

Some preliminary results on field resistance of GCA-F_1 progenies was obtained by Ray Steinhoff (1971) on 16 progenies Tony Squillace had planted from 1955 to 1959. These progenies had been exposed only to natural inoculation for 12 to 16 years at Priest River and Deception Creek Experimental Forests. The GCA-F_1 stock on the two field plots showed 18.5 to 20.9 percent of the seedlings infected. Concurrently, controls were 48.4 to 68.0 percent infected, and natural reproduction was 62.5 to 80.1 percent infected.

Additional information on field resistance of both GCA-F_1 and GCA-F_2 stocks was obtained in 1973 from a large planting specifically designed to provide information on field resistance. Here, on an extremely high- hazard site, after 3 years of field exposure and with 2 years of rust infection visible, GCA-F_1 stock was 31 percent infected, GCA-F_2 stock 12 percent infected, and controls 76 percent infected (Bingham and others 1973). After 7 years of exposure and 6 years of visible rust, F_1 stock was 47 percent infected and 9 percent dead due to rust, F_2 stock 27 percent infected and 4 percent dead, and controls 92 percent infected and 27 percent dead.

Our latest and longest duration information now comes from Tony Squillace's 1955–59 outplantings. Visiting scientist Dr. Ray E. Goddard from the University of Florida and Geral McDonald reexamined Tony Squillace's plots in summer 1980. Now 21 to 26 years after first exposure to natural inoculation, GCA-F_1 stock was 31 to 48 percent infected; controls, 69 to 86 percent infected; and natural reproduction 86 to 99 percent infected, on three outplanting plots.

It begins to appear, particularly in low-rust-hazard areas, that the level of field resistance will indeed be higher than that determined experimentally under artificial inoculation.

IMPROVEMENTS IN PROGENY TESTING PROCEDURES

II, B—moderate priority: reducing the time and cost while increasing the accuracy and sensitivity of pollination and progeny testing work.

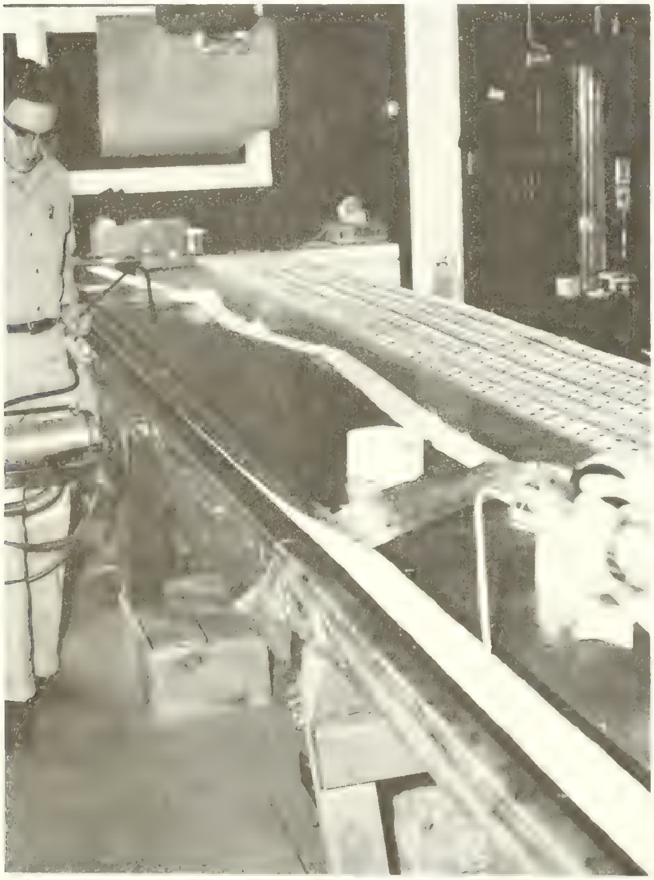
As already mentioned, the newer progeny tests of the 1960's were made using series of four heavily fruiting GCA parents as testers in a 4-tester factorial cross, as well as a 10-randomized block design with 16 seedlings per test progeny row-plot. This pollination and test procedure proved to be considerably less expensive for detecting new GCA trees and more sensitive for heritability analyses of resistance (Bingham and others 1969; Becker and Marsden 1972; Hoff and McDonald 1980b) or for heritability analyses of height growth (Hanover and Barnes 1963; 1969).

By 1964 seed were presown on stenciled, 10-block long, biodegradable paper strips immediately after extraction in the greenhouse, and up to 75,000-seedling progeny tests were fall-sown in the nursery in predivided and tagged nursery beds in the course of a single day (fig. 13). Thus, we had abandoned seed stratification and merely overwintered seed in the nursery beds.

We were also trying to remove controllable variation from the artificial inoculation process. We sheltered the ends and edges of seedling beds with water-soaked burlap during inoculations, and we tried to even out inoculum differences inherent in leaves from different Ribes spp. plants by detaching and mixing up the leaves as they were spread out on nursery bed screen-covers placed above the pine seedlings. We met with only limited success, with inoculation intensity across the block, even within the same block, still varying widely (fig. 9). (See also Patton [1972] and Bingham [1972] for unsolved problems with degree and uniformity of artificial inoculations.)

One of our more common-sense improvements came from Hoff and McDonald's studies of the spots-only syndrome. On their recommendation, we moved the time for rust examination from summer and fall to spring, usually in June. This greatly improved our capabilities for detecting shedding of spotted needles.

We also tested the reliability of single, mixed-pollen crosses for reflecting average performance of selections as based on the 4 tester crosses of the standard factorial cross. Based on percentage of infection, crosses that were made with equal volume mixtures of the pollens of the 4 testers or with those pollens plus pollens of 6 other trees (10-tree mixes), reflected the average tester cross quite closely. One year mixed-pollen crosses underestimated percent of infection determined from the average tester cross, while a second year the mixed-pollen crosses overestimated percent of infection. The 10-pollen mixes generally were more reliable in that percentages of infection deviated less from the average of the 4 tester matings (Bingham 1967, 1968). The mixed-pollen crosses, however, never were used in our first-phase progeny testing program. Results came rather late. Also, they were less sensitive crosses for heritability or other analyses we wished to make.



(A)

(B)

Figure 13.—How we handled the really large progeny test seed sowing jobs after 1960. (A) Seed spots were stenciled onto a strip of biodegradeable toweling using a sprayed dye solution (left). Then a biodegradeable methyl cellulose adhesive was dropped on each stenciled seed spot and the desired number of seed dropped thereon. The 10-block-long strip of toweling was then dried (at rear on table), cut apart at block lines, and stored till sown outdoors. (B) Seed on paper-towel strips were sown in the Moscow, Idaho, blister rust nursery in the fall and covered with sand. When germinated they were thinned so that there was one seedling per planting spot, or 16 seedlings for each test progeny per randomized block.

SEED ORCHARD TECHNOLOGY

I, C—moderate priority: studies in *P. monticola* seed orchard technology.

From 1960 on, with good levels of resistance in store, seed orchards looked more possible. We began investigating vegetative propagation, cone and seed yields in seedling and grafted trees, and other matters of P. monticola seed orchard technology that would set the character and size of future seed orchards.

We established that average cone and seed yields for young P. monticola trees in nature were 28 cones with 104 filled seed per cone, or 2,900 seed/tree/year (Bingham and Rehfeldt 1970). Then, using the same 18-year records, we analyzed the factors affecting periodicity of yield in nature (Rehfeldt and others 1971). We also established the extent of insect-caused cone and seed losses in *P. monticola* and showed that in certain areas and seed years, cone beetles (*Conophthorus ponderosae* Hopkins) destroyed 90 percent of the cones, while cone moths (*Eucosma recissoriana* Heinrich and *Dioryctria abietivorella* [Grote]) attacked and partially destroyed 50 to 85 percent of the cones (Barnes, Bingham, and Schenk 1962). Even the isolation of *P. monticola* (as at Moscow, Idaho, about 10 miles from the nearest natural stands of the species) failed to eliminate the cone moth, and we wonder when the cone beetle will enter the scene there. Seed orchard insect controls still remain to be developed.

Barnes and Bingham (1963a and b), on plots installed by Tony Squillace, also investigated top-grafting of young scions into large and reproductive mature trees, as well as 5-year effects of field fertilization, cultivations, and irrigation for "inducing" strobilus development on P. monticola seedlings 6 to 11 years old. None of these field treatments seemed to have much effect in hastening or increasing strobilus bearing in the young trees. But the three cultural treatments, alone or together in any combination, definitely affected growth. Meanwhile at the Moscow breeding arboretum—under a regime of sprinkler irrigation that added 10 to 15 inches (25 to 40 cm) of diluted sewage effluent, along with clean cultivation—more than 16 percent of 11-year- old P. monticola trees bore female strobili.

We also have had opportunities to study clonal variations and effects of graftage on cone and seed production, basing our observations on the 17-acre grafted seed orchard established mainly by Jim Hanover at Sandpoint, Idaho, in 1960 (Bingham and others 1963). First, Hanover (1962) showed that individual ortets varied in graftability, and that through 20 months success in grafting was apparently associated with vigor of ortet-shoots used for grafting. Then we noticed that 6 of 13 of the ortets were to some extent incompatible with the nursery- run, Kaniksu National Forest rootstocks. Incompatibility was delayed for up to 13 or more years (Hoff 1977). Later Ray Hoff and Geral McDonald (1978) demonstrated a highly significant difference among the ramets of the 13 ortets in intensity of infection by a needle blight disease associated with a *Lecanostricta* species. Despite trouble with scion-stock incompatabilities, cone and seed production at the Sandpoint grafted seed orchard has been spectacular. In 1980, an otherwise good cone year, and 20 years after orchard establishment, many grafted trees were producing a bushel of cones and a half-pound (225 gm) of seed apiece. This same year, the older (25 to 29 years) F_1 trees of the Moscow Breeding Arboretum were producing only about 31 cones and 1,209 filled seeds per tree. And at Moscow there still seemed to be a pollination problem, as witnessed by the very low yield of 39 filled seed per cone (Hoff, personal communication).

Developmental Work

ESTABLISHING SEED ORCHARDS

Our program of fundamental and applied research of the 1960's provided most of the answers we needed to determine the genetic structure, kind, size, and location of seed orchards for production of blister rust resistant P*P. monticola* planting stock for the Inland Empire. The only important information still lacking was on the importance of elevation-associated variation in *P. monticola* and on the long-term field resistance of the selected GCA-F_1 and GCA-F_2 progenies. By about 1968 we were ready to plan the structure and establishment of seed orchards.

First, however, the Forest Service units cooperating in the R&D program had to make some basic decisions and assumptions about the character and size of the first-phase seed orchards:

1. We would produce only GCA-F_2 seed in seed orchards composed of resistant GCA-F_1 seedlings.
2. The genetic base of the orchards would be pegged at about 100 GCA trees we had found in the 400 rust-free selection base, but more stability of resistance would be sought by selecting for a variety of resistance reactions (and presumably, resistance genes) in the individual GCA-F_1 seedling orchard foundation stocks.
3. There appeared to be significant elevation-associated variation in *P. monticola*. We assumed that an arbitrary division of selections, planting sites, and seed orchards among low- (below 3,500 ft, or 1 065 m), mid- (over 3,500 to 4,100 ft or 1 066 to 1 250 m), and high-elevation (over 4,100 ft) zones would be used to control maladaptation of seed orchard planting stocks. These three zones were estimated to comprise about 32.5, 50, and 17.5 percent, respectively, of the 2 million acres of Inland Empire white pine lands.
4. The size of the seed orchards would be determined by the following considerations:
   a. Trees would be spaced at 20 ft by 20 ft (6 m by 6 m) in orchards, and reserve stock would be maintained by planting two foundation stocks at each planting spot.
   b. For the time being we would plant resistant stocks only in the better 1 million acres of white pine lands where (as rotation age is set between 50 and 100 years) 1 to 2 percent (or 10,000 to 20,000 acres) of these lands would become available for planting annually—through clearcutting, underplanting of shelterwood cuts, or wildfires.
   c. The conservative assumption—that field resistance would not exceed the 65 percent found experimentally under artificial inoculation—would hold, and also assuming tubed planting stock and high planting survival, then the desired stocking of about 200 fairly evenly spaced trees per acre (at about 15 ft by 15 ft spacing; i.e., 500 trees per ha at 4.5 m by 4.5 m) would be attained by allowing for 35 percent rust losses and planting at about 300 trees per acre (at about 12 ft by 12 ft spacing; i.e., 740 trees per ha at 3.6 m by 3.6 m).
   d. Under routine nursery practice, there would be a 50 percent loss between numbers of filled seed and numbers of plantable seedlings.

5. Orchards would be situated where isolated from natural white pine stands and where seed production would be favored by relatively long, high-temperature growing seasons and the application of irrigation water.

6. These first-phase seed orchards, once in production, probably should not be used for longer than 20 years—or beyond the date when broader based materials of sufficient field resistance become available.

These assorted decisions and assumptions largely set the size, type (seedling), and general locality of the three seed orchards, and to some extent, established their genetic structuring.

SIZE AND LOCALITY OF SEED ORCHARDS

The specified planting of resistant F_2 stocks at 12 ft by 12 ft (3.6 m by 3.6 m) spacing would require 302.5 trees per acre, so that the total number of seedlings required to plant 20,000 acres per year would be 6,050,000. Using the figure of Bingham and Rehfeldt (1970) of 2,900 seed per young *P. monticola* tree per year (probably conservative because figures come from uncultured, natural-stand trees), the 109 trees spaced 20 ft by 20 ft (6 m by 6 m) on each acre of seed orchard would produce 316,100 filled seeds (781,000 per ha). After 50 percent are lost in the nursery, about 158,050 plantable seedlings remain (390,550 per ha). Thus, for an annual production of 6,050,000 plantable seedlings, almost 40 acres (16 ha) of seed orchards would be required.

Fortunately, the problem of locating and securing lands for the seed orchard was quickly solved. Through the foresight of former Coeur d'Alene National Forest Supervisor Ray Hilding, a quarter-section (160 acres; 65 ha) of relatively flat, marginal-agricultural lands with *Pinus ponderosa* Laws. and *P. contorta* Loud. stands had been held despite its demonstrated value for lands trading and consolidation. It was 5 miles (8 km) or more distant from natural white pine stands, had a relatively long growing season, and probably would be underlain by aquifers adequate for its sprinkler irrigation. Thus it was that 27 acres (11 ha) of this quarter-section, located near Lone Mountain on the Rathdrum Prairie northwest of Coeur d'Alene, Idaho, were to be dedicated to *P. monticola* high- and mid-elevation seed orchards. The area since has become a center for Forest Service Region 1tree breeding work (fig. 14). Another 13-acre (5-ha) low-elevation orchard was located on otherwise useless hilly terrain along the south border of the Forest Service's Coeur d'Alene Nursery.

Figure 14.—The so-called low elevation *P. monticola* F_2 seed orchard at Lone Mountain northwest of Coeur d-Alene, Idaho.

FOUNDATION STOCKS

The 40 acres (16.2 ha) of *P. monticola* seed orchards, each double planted at the 109 planting spots per acre, would require a total of 8,720 of the resistant, GCA-F_1 foundation stocks. This number would consist of 1,526 high-elevation plants for 7 acres (2.8 ha) of high-elevation orchard; 2,834 low-elevation plants for 13 acres (5.3 ha); and 4,360 mid-elevation plants for 20 acres (8.1 ha). Thus, we would require a total of 128, 236, and 364 foundation stocks, respectively, from each of the 12 high-, low-, and mid-elevation GCA-F_1 families (see below).

Aside from the joint decision of cooperators to include a variety of resistance reactions (and probably resistance-genes) in the three elevational seed orchards, the actual structuring of resistance therein was mostly left to us researchers. Here's how we attempted to structure resistance.

The 1952 to 1967 progeny tests had tested 400 rust-free parent selections and uncovered about 100 GCA trees among them. Naturally, there were not exactly 33.33 GCA trees found for each of the three arbitrary elevational zones. In fact, we found only 24 GCA trees for one zone and then decided to use only the best 24 GCA trees as foundation stocks for each of the orchards. Thus, only the 72 best of 100 GCA trees were entered in the three first-phase seed orchards.

Then, between 1965 and 1968, after the best GCA trees for each zone had been identified, we commenced mating the 24 GCA trees for each zone in a series of 12, very large, unrelated, F_1 matings. These matings involved sometimes more than 50 pollination bags and ultimately produced more than 3,000 seed or 1,500 seedlings. The resulting 36 GCA-F_1 seed lots were sown (about 8 to 10 lots each year) between 1967 and 1970. Then they were artificially inoculated at 2 years of age. At 4 years of age the correct numbers (128 to 364) of resistant GCA-F_1 seedlings (that is, the seed orchard foundation stocks) were selected and tagged from each of the 36 GCA-F_1 progenies. Finally, in the early spring of their fifth growing season, 1971-74, the tagged seedlings representing the 12 pertinent GCA-F_1 families were outplanted into the three elevational-zone orchards.

Actual structuring of resistance was then accomplished as follows: One-third of the resistant GCA-F_1 foundation stocks in each of the 12 GCA-F_1 families, in each of the three orchards, was chosen to represent the premature-needle-shedding resistance reaction (and its presumably recessive, associated gene) of the spots-only syndrome. A second one-third was chosen to represent the short shoot fungicidal resistance reaction (and its presumably recessive, associated gene) of the spots-only syndrome. A final one-third was chosen to represent various bark reaction resistance types.

Knowing what we do today about structure of resistance in GCA trees, this artificial selection scheme promises to provide fairly stable resistance. Resistance in the presumably 65 + percent surviving GCA-F_2 seedlings coming from these seed orchards should be based on at least five (three vertical and two horizontal) types of resistance reactions. The two horizontal (or uniform) types of resistance are involved because in selecting for GCA about half of the parents also exhibit low needle lesion frequency, and 30 percent of the parents show slow canker growth.

SUMMARY

Twenty-five years of research and development work (1950–75)—first-phase work undertaken by Forest Service cooperators—has led to experimental production (and soon mass-production) of Inland Empire western white pines bred for blister rust resistance. Breeding has gone through two generations, until 65 percent of the trees resist intense, artificial exposure to the rust fungus. And unless the racial structure of the rust alters disastrously, the long-range survival of these second generation stocks under natural exposure to the rust probably will exceed 65 percent.

Resistance in the second generation stocks is based on selections for general combining ability for a combination of differential and uniform types of resistance. Some of the resistance reactions—and, presumably resistance genes—are identical to those that probably have persisted for long periods near the Asiatic white pine:blister rust gene center. Thus, resistance in these first-phase stocks will probably persist until we can produce faster growing and better adapted second-phase stocks embodying more types of resistance genes and more stable resistance.

If this R&D program has been a "success story," then it's mainly because the biological, research, and administrative climates were all ideal. R&D workers had only to rely on a large backlog of information on disease resistance in agronomic crops and to interpret correctly experiences with resistance in eastern white pine and Eurasian white pines to attain an almost certain success.

WHERE DO WE GO FROM HERE? PHASE II

As stated at the beginning of this report: "Implied in the term 'first-phase' was the idea that planting stocks would continue to be improved in subsequent programs—toward successively faster growing, better adapted, and more resistant stocks embodying more resistance genes and more stable resistance." What sort of progress have we made toward these goals in the first of these subsequent programs, labeled the "second-phase" program?

Phase II work commenced in 1967 under the Intermountain Forest and Range Experiment Station, the Northern Region, and the several "white pine" National Forests, using Congressionally appropriated, Forest Service blister rust control funds. The progeny testing part of the work is continuing today under an eight-member, cooperative, Western White Pine Tree Improvement Committee within the parent Inland Empire Tree Improvement Cooperative. Current members are the Forest Service, Region 1; the University of Idaho; the Department of Lands, State of Idaho; the Coeur d'Alene Tribe, BIA; Diamond International Corporation; Idaho Pines Timber Associates; Potlatch Corporation; and St. Regis Paper Company. Other private industry cooperators are considering membership.

In 1967, the first job undertaken by the white pine Forests was to expand the phase I genetic base of rust-free, wild-stand, "candidate trees" from 400 up to 3,200 (400 phase I and 2,800 phase II). We came within about 100 trees of attaining the 2,800-tree phase II goal—actually locating 2,698 new trees. With the 400 phase I trees, we then had 3,098 trees in hand, of which 161 later were dropped because of accidental destruction, death by disease or insects, having too many blister rust cankers, or other reasons. At present, the remaining 2,937 trees can be divided into two potential breeding populations, as follows:

Potential breeding population	Number phase II candidates including phase I trees
Northern Idaho-Northwestern Montana white pine lands less than 4,500 ft (1 370 m)	2,533
Northern Idaho-Northwestern Montana white pine lands greater than 4,500 ft (1 370 m)	404
Total number phase II candidates	2,937

Originally this 2,937-tree genetic base was to have been compartmented latitudinally and elevationally, and possibly longitudinally if found necessary according to the performance in Squillace, Barnes, or Steinhoff provenance tests. Fortunately, however, Rehfeldt (1979) and Steinhoff (1979) have demonstrated the remarkable phenotypic plasticity of *P. monticola*, removing the necessity for compartmentalizing the base except, perhaps, to remove the 404 high-altitude candidates.

It was soon apparent that little in the way of meeting the phase II program goals could be realized by breeding within the relatively small, 404-tree, high-elevation population. In fact, it appears that excluding these 404 trees from the overall phase II base population would merely be gilding the lily. The following supports this view:

1. Elevation accounts for only about 2 percent of the variation in height growth in *P. monticola* (Steinhoff 1979).
2. Even though height growth was reduced about 10 percent in progenies of high-elevation *P. monticola* trees (Steinhoff 1979), if the 404 high-elevation trees were added to the 2,533-tree low- and mid-elevation phase II population, the loss would be diluted to less than 2 percent.
3. If the low-, mid-, and high-elevation trees were all included in the same breeding population, then, barring cold injuries, we might expect an offsetting increase in height growth when seed orchard planting stocks were used on high-elevation sites.
4. Even a low-intensity family selection for fast height growth would eliminate more of the high- than the low- or mid-elevation trees.
5. Lastly, Rehfeldt's latest (1982) information shows the height differences associated with the highest elevations to be nonsignificant.

At the same time there is ample opportunity for improving the 2,533-tree low- and mid-elevation population, or the overall 2,937-tree population. Selection will take place at the conclusion of 6 years of progeny testing, using 180-tree, wind-pollinated progenies. Utility and reliability of wind-pollinated progenies for appraising resistance have increased markedly over the years as the proportion of nonresistant trees in the residual populations has been reduced (Hoff and others 1973). Selection priorities we have tentatively assigned are as follows:

First priority – Family, then individual tree selection for three uniform (horizontal) resistance types (that is, low needle-spotting frequency, slow appearance of bark cankers, and slow growth or tolerance of bark cankers).

Second priority – Individual tree selection, first for any uniform resistance types not selected above, then to four differential (vertical) resistance types including complete lack of foliar infection, premature shedding of spotted needles, short shoot fungicidal reaction, and various bark resistance reactions.

Third priority – A low-intensity, family selection for rapid, early growth rate.

Some simple arithmetic shows that if we are to meet primary phase II objectives of increasing the kinds and stability of resistance (as under first and second priority selections, above), then there will be only limited possibilities for improvement of growth rate. For instance, suppose in the 2,937-tree, total phase II base population, we are forced to drop 437 more trees because of limited cone and seed bearing, poor seed germination in progeny tests, other progeny test "accidents," extreme susceptibility of progenies, or other reasons. Then suppose we select the upper 50 percent of the remaining 2,500 trees in a family selection for low needle spot frequency. Then suppose we select the upper 20 percent of the 1,250 remaining trees in a family selection for slow canker growth rate, further reducing the base to 250 trees. Continued family selection for the third uniform trait probably would be unwise, reducing the base to less than 100 trees; so individual tree selection for the remaining uniform and the four differential traits would have to be instituted. Under these conditions, there is small promise for making family selections for growth rate for other than the perhaps upper 25 percent of the 250 trees.

The 2,937 phase II candidate trees are being progeny tested in five testing cycles running from 1976 to 1989 at the Coeur d'Alene Forest Service Nursery. Various uniform and differential resistance reactions are being identified and marked with varicolored plastic rings on individual seedlings, awaiting final family and individual progeny tree selections. Seedling seed orchards should be established between 1982 and 1989 and should bear seed by significant amounts of about 2000.

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APPENDIX

This appendix contains the material for footnotes 2 through 10 in the text. Because of the lengthy and anecdotal nature of these footnotes, they have been kept here as a separate section.

[2]An interesting sidelight on researchers developed about this time—in the 1930's. German blister rust researcher and authority, Professor C. F. von Tubeuf, had been waging somewhat of a crusade against various German forest administrators who persisted in advocating the planting of susceptible North American white pines in German State Forests (von Tubeuf 1905, 1917, 1924, 1928, 1936). Somehow von Tubeuf came across his countryman Professor J. Liese's remarks that the interracial resistance to *Lophodermium pinastri* in *P. sylvestris*, indeed might hold for *C. ribicola* resistance in *P. strobus*. Von Tubeuf's (1935) reaction, in the manner then popular in the very lively German forestry periodicals, was to publicly scold Liese, saying (the author's translation), "Liese's beliefs in relation to immune *P. strobus*, and that resistant varieties can be produced through breeding, does not help us now" (apparently in saving infected *P. strobus* stands or preventing further introductions). "Has he discussed this with Professor Dengler?" (apparently A. Dengler, a prominent German silviculturist of the time, who must have agreed with von Tubeuf). "Can he lay out for us one practical breeding plan? Has he undertaken research in this area that is favorable? I think not'!" Apparently this harangue did not much deter Liese. Later, Liese (1936) said that *P. strobus* well might display racial variation in resistance to *C. ribicola*, simply referring von Tubeuf to his (Liese's) rather definitive experiments establishing the racial variation of Scotch pine resistance to *P. pini* (1930a,b, 1936) where again he extrapolated possibly similar results in resistance of *P. strobus* to *C. ribicola*.

[3]Much of this is hearsay, but probably it's worth preserving.—The annual, summer 1949 field trip of the Idaho State Land Board (the agency that administers the education-supporting funds coming from timber cut on State lands) was under way, very grandly transported by river-drive, wanigan-raft, down the very remote and beautiful North Fork of the Clearwater River in northern Idaho. One main purpose of this particular trip was for Land Board members and their blister rust control administrator guests to consider the acceleration of timber harvesting plans in the State-owned, heavily rusted mature *P. monticola* stands that bordered the river. One exchange between a Land Board member and a now deceased but then leading blister rust control administrator was leaked to the author about as follows: Land Board Member—"I understand that University of Wisconsin researchers are already at work exploring blister rust resistance in *P. strobus*; are your people planning anything along these lines in *P. monticola*?" My informant tells me there was a pregnant pause, and then, as if suddenly remembering the lonely box of cuttings protruding from the 8th floor window in Spokane, or the single, controlled pollination attempt, the blister rust control administrator finally answered, "By golly, we're already working on that!" Perhaps this hearsay deserves some credence, for I can testify that the administrator did, a few weeks later, visit the 8th floor lab and did, as usual, casually glance at the windowbox cuttings, and then did ask me pointblank, "Shouldn't we be doing something more toward development of blister rust resistance in *P. monticola*?" Fortunately, he did not inquire into the abortive pollination. (The author has since publicly confessed that he had pollination-bagged the previous year's [but still small] cones, and later, after the pinkish and strangely different current-season strobili began to emerge from the branch-tip buds, surreptitiously moved the pollination bags where they belonged.) As Tony Squillace points out in his review of this paper, it is significant that I soon was sent to the Placerville, Calif., Institute of Forest Genetics to learn how to breed trees.

[4]It was only much later that we had sophisticated apparatus like a cone-tumbling drum to shake winged seeds from the cones, or a South Dakota air-column blower to remove debris, wings, and hollow seeds. Meanwhile, the approved methods included (1) thumping opened cones vigorously on the side of a box, bottom-screened with a mesh allowing gobs of fresh cone pitch smaller than the seeds to exit; (2) impaling larger gobs of fresh pitch on a pencil point; (3) hand chafing to remove wings (hopefully without many sticky lumps of pitch, seed, and wings); and (4) transferring the resulting mess of seed, wings, dry pitch lumps, broken needles, bud scales, and so forth, to a clean, fine-screened winnowing box. Then, firmly holding the winnowing box over a bedsheet, we made a series of about 20, ever-quickening deep knee bends. The first 5 or so moderately fast deep knee bends "floated" off the broken wings, larger pieces of needles, and bud scales. Then a meticulously executed and quickened ballet of about 15 deep knee bends at the bottom followed by a quick side shift of the seed winnowing box floated off the hollow seeds. We became expert and undeniably proud of our prowess at this exercise. In fact, all debris was removed, and cutting tests showed over 99 percent of the hollow seed removed. Nevertheless, one evening as we were demonstrating the artistry of the winnowing process to a group of visiting Forest Service brass, one of the brass dismissed the entire demonstration with one remark . . . "Ah, the Egyptians were doing that with cereals 2,000 years ago."

[5]Apparently pine squirrels (locally the Richardson's red squirrel, *Tamiasciurus hudsonicus richardsonii* Bachman) stole bagged cones only when near starvation. For instance, in 1951 a very poor year for female strobilus production, coupled with a late June frost, killed most of the already scarce *P. monticola* and *Pinus contorta* Dougl. (lodgepole pine) strobili on two of our selection areas. It developed that the *P. monticola* strobili protected from frost damage by our already installed pollination bags constituted a large proportion of the cones that would mature in the area in the fall, one year later. Thus, one year later the squirrels there were desperate for food, and they went to work on our cone bags. In one selection area the squirrels cut off and lugged away all the bagged cones we had managed to pollinate. In another area, they demonstrated a remarkable selectivity in their thefts. The squirrels had bitten through the folded necks of the cone bags, cut off at the peduncles all eight cones representing the intraspecies cross (*P. monticola* × *P. monticola*), dropping them down about a foot into the bottoms of the pendulous cone bags. Then they had somehow clung to the swinging bags, chewed small holes in the bottoms of the bags, and fished out the almost mature cones through those very tight-fitting holes. They missed only one of the cones. It was found, along with some seeds from other cones, lying in the bottom of a holed bag, and when extracted contained 206 filled and 1 hollow seed. The eight cones representing the interspecies cross (*P. monticola* × *P. koraiensis*), however, were almost ignored by these squirrels. These cones contained more than 1,000 seeds, but every one was hollow

(Wright 1959; Bingham, and others 1974—both report that repeated attempts to produce this hybrid have resulted in only a few filled seeds of doubtful hybridity).

[6]Five-pound size, cotton flour sacks—the standard blister ruster's nosebag in which he carried his sack lunch tied to his belt at the small of back—were used as cone bags. These flour sacks, apparently constructed from yard goods textile millends, were a never-ending surprise and delight. They were printed in a wide variety of brightly colored and imaginatively patterned checks, calicos, and floral designs for use by thrifty home seamstresses. A tall white pine bagged with these flour sacks indeed was a sight; surprisingly the wildly colored bags did not deter the squirrels or cone insects from attacking unbagged cones.

[7]This soil plug cutter had been well-designed by John Breakey and worked beautifully in the loam soils at Fernwood and Elk Creek, Idaho, plots; but it was another matter when we transplanted into the compact, rocky-gravelly soils of the Randolph Creek, Mont., plot. As shown in figure 6, the plug cutters had stout, T-bar pipe handles and foot "rests," the latter on which the operator jumped—once in loam soils and repeatedly in gravelly-rocky soils—to drive the cutter down to the desired depth, attained when the footrests contacted the ground surface. At Randolph Creek, we transplanters all developed a chronic soreness of the feet soon known as "plug-cutter's instep." And later, as we crawled for days on end examining small seedlings for rust, this same gravelly-rocky soil was associated with another malady known as "progeny tester's knee."

[8]This Steering Committee had as members most of the then very few northwestern and California forest geneticists, a few local agronomic crop breeders, forestry faculty silviculturists from local universities, a few blister rust pathology and white pine silviculture researchers, Blister Rust Control, FS Division of Timber Management administration, and Northern Rocky Mountain Forest and Range Experiment Station personnel. It was the forerunner of the Northwest Forest Genetics Association.

[9]In late August 1957, Tony Squillace and the author, along with assistants Doyle Romans, George Blake, and Bob Hill, had just concluded the usual 2-week session inspecting for rust and resistance reactions, measuring tree heights, and weeding and otherwise maintaining progeny tests on the Fernwood, Idaho, field outplanting plot. At the end of the day the five of us sat together on a satisfyingly large and soft pile of weeds just cultivated from the progeny test rows, and we talked about where we might go from there. It had become apparent to us that blister rust resistance in Inland Empire western white pine was under strong genetic control and that resistant planting stocks should be attainable. As I remember it, it was Tony who first voiced the obvious question, "Well, now that we've got resistance, what are we going to do about it?"

We decided we could progress most rapidly toward a practical level of resistance if we could now "take the program out of the woods" into some nearby, long-growing-season area. Our erstwhile Californian cooperator, Jack Duffield, had recently transferred from the Forest Service to lead a new genetics program at Nisqually, Wash., for the Industrial Forestry Association. There, Duffield had just completed planning and constructing a $17,250 facility that included an office lab building, greenhouse, headhouse, lathhouse, and a garage-storage building. This research facility seemed to meet our small needs as well, and if we could only find a couple of suitable and free acres of land to put it on, along with a small nursery, plus 40 nearby acres for a breeding arboretum, we would be all set. Then the impromptu bull-session dissolved as we hurried from the weed pile to the carryall vehicle and back to Clarkia in time for dinner.

At the dinner table, Homer Hartman, supervisor of the local blister rust control force, told us that some brass from the Forest Service Washington Office and the Regional Office in Missoula, Mont., were inspecting blister rust control work to the north around Priest Lake, Idaho. Unbelievably, they were running a day ahead of schedule, and wanted to spend their extra day reviewing the new resistance research. So it was that arriving at Clarkia that evening were Assistant Chief of the Forest Service for State and Private Forestry, Bill Swingler; his Deputy Assistant Chief for Disease Control, Connie Wessela; Region 1 Regional Forester, Pete Hansen; and his Assistant Regional Forester for the Division of Blister Rust Control, Swanny Swanson.

The next day we ferried the inspection party, in two carryalls, first to nearby Crystal Creek to observe rust-free selections in the wild—their healthy branches often interlaced with multicankered branches of nearby, rust-susceptible trees. We saved the *piece de resistance* (pun unintended)—the Fernwood Progeny Test Plot—for the last. Luckily the four successive progeny tests, then 1 to 4 years after being artificially inoculated, were in one of their more striking phases. On the one hand, in the youngest test were heavily needle-spotted row-plots of trees from susceptible progenies alongside lightly spotted or almost unspotted row-plots of trees from resistant progenies. On the other hand, in the oldest test were clearcut, red-foliaged row-plots of dead and dying trees of control or other susceptible progenies, often alongside the surviving, green-foliaged row-plots of resistant progenies. After acquainting the inspectors with the 10-seedling row-plot, randomized block design, we suggested they (1) recall the four rust-free parent selections (17, 19, 22, and 58) that they had just finished viewing in Crystal Creek; (2) search out on the row-plot stakes those progeny row-plots having those four selections as one or especially both parents; and (3) inspect the trees in those row-plots closely and carefully, comparing them to trees in adjacent row-plots.

The inspectors dispersed into the progeny tests and we researchers resumed our soft roost on the weed pile; it was highly satisfying to see them emulating our behavior of the last 2 weeks—on their hands and knees, crawling in the narrow aisle between row-plots and peering closely, heads down and tails up, at the small, mostly 6- to 18-inch (15 to 45-cm) trees. After many head-to-head discussions across progeny rows, and after numerous questions to us researchers, the inspectors joined us on the weed pile.

Assistant Chief Swingler probably crawled down the most rows and peered at the most seedlings; at least he was last to return to the weed pile. Then, having just barely taken a companionable seat on the pile, he thoroughly startled Tony and me by paraphrasing Tony's question of the previous late afternoon: "Well, it looks like you're onto something here. What do you think you should be doing about it?" I flicked Tony a glance, and while he seemed to be preoccupied, he did manage

a small nod. Then with a hardly perceptible pause, I launched into an extrapolated version of the previous day's discussion, hoping to leave the impression that the lists of new research jobs and people, research facilities, and operating funds were the result of long and deliberate discussion. Nobody had to write Bill Swingler, or for that matter the other three inspectors, a letter. Bill responded, "Okay, it sounds reasonable. Now you find some free lands for your proposed research installation and I'll see if I can find the money."

About 2 weeks later Connie Wessela was on the scratchy, rural telephone line, calling from Washington, D.C., and saying, "Bill Swingler has raised the $17,250 for your building. Now you get going on the land!" Then Tony and I spent a frantic 2 weeks searching the warmer, western edges of the northern Idaho white pine country for 40 or so flat and potentially free acres of National Forest, BLM, or even State land. We were even beginning to consider purchasing private lands. Then Dean Ernie Wohletz of the College of Forestry, University of Idaho, relayed the welcome news that, because the University Agronomy Department was moving off some campus lands, 40 acres of fertile Palouse farmlands would become available on the University Farm about a mile west of the main campus against the Washington State line. The dean also said a couple more acres would be available from the Forest Nursery (nearer the main campus, along Moscow, Idaho's Main Street) for an office-laboratory-greenhouse-nursery facility.

Within another 2 weeks University-Forest Service cooperative agreements were signed covering free use of these university lands for the establishment of a "Northern Idaho Forest Genetics Center." Almost immediately we began balling, potting, transporting, and transplanting truckloads of 1- to 2-ft (30- to 60-cm) tall, rust-resistant, F_1 seedlings (about 1,000 trees) from the three Idaho and Montana outplanting plots onto the new University Farm Breeding Arboretum (fig. 15A and B). Currently, the Genetics Center is an annex off the larger Intermountain Forest and Range Experiment Station's Moscow Forestry Sciences Laboratory that was constructed in 1963 (fig. 16).

[10]From results of the 1952 progeny test (tables 7 to 9), we earlier workers had concluded that major genes could not be associated with the resistance we had measured and, instead, that resistance was quantitatively inherited. Thus, the conclusions drawn from the early test were opposite those from Ray and Geral's tests, and there was no explanation we could suggest to explain the discrepancy. Fur flew when the two scientists first approached me with partial results from a single progeny test. The problems of the cereal rust resistance breeders with collapsing major gene resistance had been pounded into me until dominant and recessive resistance genes had become almost anathema to me—especially when they cropped up in someone else's data. Ray and Geral emerged from the first few stormy sessions with me somewhat battered, but unbowed. Then, styling themselves as the "young Turks," and trailing a somewhat less than real aroma as downtrodden young scientists, they produced more evidence of major-gene-control of the spots-only syndrome from other progeny tests and from self-pollinated progenies. Slowly they coaxed or prodded me into their corral until I reached the point where I was almost enthusiastic about their major-gene hypothesis. Now I have to admit that their persistence and open criticism had become one of my strongest assets as a research administrator.

(A)

(B)

Figure 15.—The Moscow, Idaho, Breeding Arboretum: Photo A.—at the time of establishment in 1957. Photo B—20 years later in 1976.

Figure 16.—The Northern Idaho Forest Genetics Center, 1958; now an annex to the Intermountain Station's Moscow, Idaho, Forestry Sciences Laboratory.

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Methods, results, and conclusions are reviewed for a 25-year, USDA Forest Service first-phase Research and Development program. The program goal was to attain useful blister rust resistance in western white pine. One study result is that the Service will be mass-producing second-generation, rust resistant white pines for the Inland Empire. About two-thirds of these seedlings are expected to withstand severe exposure to local races of blister rust. The resistance is based on a number of differential and uniform types. Second-phase work, aimed for fruition before the year 2000, is outlined.

KEYWORDS: host:parasite systems, vertical resistance, geographic variation, altitudinal variation, *Cronartium ribicola, Pinus monticola,* disease resistance, horizontal resistance, tree resistance, seed orchard technology

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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A Management Decision Framework for Winnowing Simulated All-Aged Stand Prescriptions

Dale O. Hall
John A. Bruna

RESEARCH SUMMARY

Forest managers have a vast spectrum of stand prescriptions and regimes from which to choose. Evaluation to find the optimum prescription for a specific stand, or class of stands, could take days or weeks. The methodology for evaluating uneven-aged and all-aged stands has been especially limited. Forest managers need a quick and effective procedure for finding the optimum all-aged prescription for a specific stand.

The forest owner's management objective provides the scale for judging an optimum prescription. The objective is usually to maximize some measure of biologic or economic productivity. Productivity measurement units are frequently: (1) periodic annual increment (PAI) in cubic foot volume (PAICV); (2) PAI in merchantable volume (PAIMV); (3) present net worth of future incomes (PNW); and (4) land (soil) expectation value (LEV). The first three are well known. LEV solutions for all-aged stands have been available only since 1980.

Iterative methods are commonly used to find the one prescription with the greatest estimated productivity. In these methods the productivity of the first prescription is estimated. Then, one prescription element is stepped, up or down, and the next prescription evaluated. When all elements have been varied (stepped) within appropriate limits, the prescription with the maximum estimated productivity, and meeting all constraints, is selected.

Stage's Prognosis Model is used for simulating stand growth and estimating productivity per acre in cubic and board foot volumes. The need for a large number of prescription iterations based on the model suggests an executive ADP program to efficiently build and index prognosis stand files and quickly submit the many prognosis jobs. The WINNOW programs were developed to meet this need. As many as 10 prognosis jobs per minute can be submitted through WINNOW.

Stand biological productivity is read from the prognosis job output for each trial cutting cycle. The tree value classes and a simple set of desk calculations provide the LEV. The tabulated biologic and economic productivity results clearly indicate relations between trial prescriptions so managers can select the optimum prescription for the specified objective.

The WINNOW procedures were used in 1980 to evaluate a stand of ponderosa pine for the Idaho Department of Lands. The legislated objective equated with maximum LEV—the revenues support Idaho schools. Uneven-aged management had been prescribed. A total of 18 stand options were evaluated for each of three cutting cycles—54 stand prescriptions. The indicated optimum stand prescription showed potential productivity increases over current annual growth as:

LEV, dollars/acre(/ha) \$8 to \$36 (\$19 to \$89)

PAICV, ft^3/acre (m^3/ha) 85 to 112 (5.95 to 7.84)

PAIMV, bd.ft./acre(/ha) 230 to 473 (568 to 1,169)

The stand was immediately marked (1981) to approach the optimum prescription.

THE AUTHORS

DALE O. HALL (retired) was a research silviculturist with the Intermountain Forest and Range Experiment Station at Boise, Idaho, from 1967 to 1982. He has studied ponderosa pine regeneration practices and thinning schedules. Economic management of western conifers has been a primary interest for many years. He holds forestry degrees from the University of California (B.S., 1951; M.F., 1958) and the University of Georgia (Ph.D., 1977).

JOHN A. BRUNA joined the Southwest Area of the Idaho Department of Lands in 1976 as timber management forester. He is presently the Area forest improvement forester and project leader for the stand release and growth monitoring program. He has a B.S. degree (1975) in forest resource management from the University of Idaho.

A Management Decision Framework for Winnowing Simulated All-Aged Stand Prescriptions

Dale O. Hall
John A. Bruna

INTRODUCTION

"Winnow:...to remove...to get rid of...to separate desirable and undesirable elements" (**Webster's New Collegiate Dictionary**, 1977).

In our research we apply the term "winnow" to the selection of one, best, all-aged stand prescription from among many possible prescriptions. There could be many prescriptions, for instance, for the stand pictured in figure 1. But which would be the best silvicultural/managerial prescription? (For a definitive answer for this stand, see the case study later in this paper.)

Sound prescriptions will, implicitly or explicitly, recognize and consider the owner's objectives, land productivity, and site protection. Land productivity concerns should include a balance of forage, timber, and water production, of wildlife habitat maintenance, and of human amenities. Site protection recognizes the controlled occurrence and judicious use of fire. Soil productivity is maintained by reducing compaction and erosion and by increasing fertility. Vegetation is maintained to protect the site and is controlled to meet productivity objectives and limit losses caused by insects and disease. Prescriptions must be economically feasible and consider the biological requirements of stands for regeneration, growth, and control of mortality agents. But even with these considerations, the owner's objectives generally provide the test for a "best" prescription and the units for measuring the approach to "best."

An all-aged stand prescription has at least five elements (Alexander and Edminster 1978; Gibbs 1978): four prescribe the reserve stand at the start of the growth period, and the fifth defines the cutting cycle. The elements are:

1. Species composition - percent by volume or basal area of each species.
2. Stand structure - the distribution of trees by age-size (diameter) classes.
3. Maximum tree size (diameter) - the largest tree retained in the size distribution.
4. Stand density - a quantitative measure of tree stocking in absolute terms, generally total basal area per unit area.
5. Cutting cycle or interharvest period (Hall[1]) - the time between successive cuts in a stand (after Ford-Robertson 1971).

Using these elements, an abbreviated code identifies each prescription. For example:

PP60DF40-1.20-16-60-12 (English), or
PP60DF40-1.20-40.6-13.8-12 (metric)

identifies a stand with these characteristics:

Species composition, percent basal area: ponderosa pine 60, Douglas-fir 40
"q" structure, 2-inch (5-cm) classes: 1.20
Maximum reserve diameter at breast height (d.b.h.), inches (cm): 16 (40.6)
Reserve stocking, basal area, ft^2/acre (m^2/ha): 60 (13.8)
Cutting cycle, year: 12

Despite such lists of objectives and elements, an answer as to which is the best all-aged prescription for a particular stand has not generally been available. We would like here to discuss the question and to give an objective procedure for selecting all-aged prescriptions. We assume a rational decisionmaker with a social conscience and resource concerns that extend over many generations.

Figure 1.—What is the best silvicultural/managerial prescription for this stand of ponderosa pine near New Centerville, Idaho. (Photo by John Bruna, Idaho Department of Lands.)

[1]Hall, Dale O. Uneven-aged stand decisions for optimum productivity. Manuscript in preparation.

STAND GROWTH ESTIMATES AND OPTIMIZING TECHNIQUES

Two important steps in identifying a "best" all-aged prescription are the estimation of growth for each trial prescription and the selection of an optimum. The growth of a prescribed stand is simulated and compared with the scale for optimum. The more accurate the growth projection, the better the odds for selecting a true optimum.

Growth projection techniques range from relatively simple stand table projections (Husch 1963), to more complex matrix solutions (Usher 1966), and to sophisticated computer models that use differential equations (Stage 1973; Adams and Ek 1974). The reliability for growth projection of one technique over another has not been demonstrated (Hann and Bare 1979).

Hann and Bare (1979) reviewed progress in optimizing techniques. They stressed Adams and Ek's (1974) nonlinear mathematical programing approach. Rorres (1978) and Buongiorno and Michie (1980) have used linear programing techniques. All these techniques require knowledge of sophisticated mathematical concepts and procedures, knowledge not usually available to field foresters. A second problem is that some solutions already exceed computer capabilities (Adams and Ek 1975).

Iterative optimizing techniques have been used with even-aged management (Larsen 1977) for many decades (Bentley and Teeguarden 1965). An iterative approach has recently been described for uneven or all-aged stand management (Chang 1981; Hall[2]). Hall uses a sophisticated and widely used growth simulator (Stage 1973) with some relatively simple computational procedures. There are two primary disadvantages: the method uses a "q" stand size distribution (Husch 1963[3]) that may be suboptimal; and a large number of projections are necessary to identify the "best" prescription.

The question of what measure to optimize is the owner's choice. Should it be based on biologic productivity—periodic annual increment in cubic volume or in merchantable volume? Or on some economic measure—internal rate of return, or land (soil) expectation value, or forest rent? All have their proponents. Most forest management texts discuss the relative values of each. The owner must clearly state a choice. This becomes the yardstick for the "test of best," the decision criterion.

Usually the "test of best" is constrained by some biologic, economic, sociologic, or managerial limits (table 1). Constraints, in our situation, must be expressed in terms of prescription elements or variables in the simulator. This may require some transformations and interpretations. For instance, deer or elk hiding cover is "vegetation capable of hiding 90 percent of a standing adult deer or elk from the view of a human at a distance equal to or less than 61 m (200 ft)" (Thomas and others 1979, p. 109). This may be interpreted as the relative number of small trees per acre with all-aged systems. Stand structure and density control the number of small trees (table 2). These relationships permit "deer and elk hiding cover" to be transformed to a constraint in terms of stand structure and density.

Evaluating prescriptions with different sets of constraints is one way of finding the relative values for potential trade-offs. After our initial discussion with a single set of constraints, we will look at some alternative constraints—trade-offs.

[2]Hall, Dale O. Financial maturity: for even-aged and all-aged stands. In press.

[3]Husch substitutes the symbol "r" for traditional "q".

Table 1.—Some effects of constraints on stand management options

Constraint	Effect
Tree size limits	Seed production potential
	Merchantable volume
	Tree value
	Equipment size (logging)
	Size of regeneration opening
Stand density	Seed germination
	Seedling survival
	Tree growth rate
	Relative proportion of merchantable volume
	Type and degree of site preparation possible
Interest rate	Land value
	(Max) tree size
	Merchantability limits
	Stand density
	Length of cutting cycle
Cutting cycle	Proportion of disturbed soil
	Amount and degree of compaction
	Proportion of stand harvested
	Area of annual cut
	Size of field crew
	Annual road maintenance
	Amount of slash developed

Table 2.—Number of small trees per acre (ha) as influenced by stand structure (q) and density (basal area)

DBH class		Basal area density					
		65 ft² (14.9 m²)				80 ft² (19.5 m²)	
Inches	*cm*	*q = 1.10*	*q = 1.20*	*q = 1.30*	*q = 1.50*	*q = 1.10*	*q = 1.20*
1.0-4.9	2.5-12.4	51 (126)	70 (173)	103 (255)	156 (385)	61 (151)	96 (237)
5.0-8.9	12.5-22.6	43 (106)	49 (121)	61 (151)	69 (170)	51 (126)	66 (163)

Setting a decision criterion and set of constraints will provide sideboards to the range of trial prescriptions to be tested (fig. 2). Experience in evaluating prescriptions will also tend to reduce the range of trial prescriptions. Two sets of prescription element values should be considered: one for initial trials and another for refining decisions (table 3). These sets are like a marksman's "zeroing round" and "match round."

Table 3.—Range in prescription values for initial and refining trials

Prescription element	Initial trials	Refining trials
Species composition	0.20–0.30	0.05–0.10
q	.20– .30	.05– .10
D.b.h., inches (cm)	3–4 (7–10)	1–2 (2–5)
Density, ft²/acre (m²/ha)	10–20 (2–4)	5 (1–1.5)

FOREST: ______ DECISION CRITERION: *Maximize Bare Land Value* PLANNER: *Hall and Bruna 2/10/81*

COMPT: *Boise Basin* HAB.TYP: *PF/CARU* NBR PROJ: i*j*k*l*m= *30*

STAND: ______ LOCAT: ______

CONSTRAINTS: Discount rate 1.*05*; *STMPG appreciation rate = 1.03 Q ≥ 1.10; to insure reasonable quality selection options. Max. d.b.h. ≥ 16" to insure adequate seed for regen. Res. STKG ≤ 65 ft.² b.a. to maintain light and moisture for repro. Cut CYC ≥ 12 yrs. to limit organization impacts. CF yield ≥ .90 CF potential to keep supplies high. CF harvest ≤ .50 CF VOL/AC to limit impacts on STD. BF harvest ≥ 2 m.b.f./AC to make logging profitable.*

REMARKS: *BAI MULT = 2.15*

(1×2×3×3)+(1×2×2×3)= 30

PRESCRIPTION ELEMENTS:

(1) Spec Comp-(S_i)

Units - *FT² b.a.*

Sp	Code	Pct
A	*PP*	*100*
B		
C		
D		

MEASUREMENT UNITS

a) *PAI, CF* b) *PAI, BF* c) *CF, CUT %* d) *Bare land value $*

(2) Q_j q	(3) M_k Max dbh	(4) D_l Res stk	(5) C_m Cutting cycle 12	14	16
1.10	*14*	*55*			
		60			
		65			
	16	*55*			
		60			
		65			
	18	*55*			
		60			
		65			

(2) Q_j q	(3) M_k Max dbh	(4) D_l Res stk	(5) C_m Cutting cycle 12	14	16
1.20	*14*	*55*			
		60			
		65			
	16	*55*			
		60			
		65			
	18	*55*			
		60			
		65			

(2) Q_j q	(3) M_k Max dbh	(4) D_l Res stk	(5) C_m Cutting cycle 12	14	16
1.30					
	16	*55*			
		60			
		65			
	18	*55*			
		60			
		65			

Page 1 of *1*

INT-1208-DOH 1/81

Figure 2.—All-aged stand decision set selection and tabulation form for case study.

THE WINNOW PROCEDURES

Iterative procedures require examining a large number of alternative prescriptions to find the best one. The process is much like the winnowing of chaff from edible grain. Hence, the system of procedures and computer programs is named WINNOW (Hall[4]). The WINNOW iterative procedures are used to compare the estimated productivity of many all-aged stand prescriptions under a stated decision criterion and set of silvicultural-managerial constraints.

The automatic data processing (ADP) costs for the WINNOW procedure are generally controlled by the number of stand projections required. ADP costs will vary between installations. Our 1981 costs per projection were slightly less than $1.00 at Washington State University Computer Service Center. Costs for storage of WINNOW stand files is controlled by regularly deleting files as evaluations are completed.

We make a number of explicit assumptions in using WINNOW:

1. All-aged management has been selected.
2. Prescriptions are closely attainable in the field.
3. Reserve trees are selected with a conscious effort to maintain and improve growth and quality potentials.
4. After each harvest (at start of each growth period) a stand exactly matches its prescription.
5. Interharvest periods will not vary.
6. "q" values are for 2-inch (5-cm) d.b.h. classes.
7. Stand growth response to each trial prescription closely follows the simulator estimates.
8. Natural regeneration is adequate to maintain stand structures.
9. Economic variables change as predicted.
10. Costs of controlling stocking of submerchantable trees, after harvesting operations, are similar for all stand prescriptions and are nominal. (We made this assumption to simplify our explanation. The user could include such costs when needed, discount them, and include with other cost terms.)

Definitions and equations used in WINNOW are summarized in table 4.

We recognize that volume and value estimates are short-term estimates of limited reliability. We make a strong recommendation for applying the results of this, or any similar evaluation:

Continually monitor actual stand growth and value productivity for selected prescriptions. Reevaluate stand prescriptions as site specific productivity data become available.

In our discussion we do not consider the transition path from a present stand to some desired future stand. Hann and Bare (1979) discuss integration of stands into a forest regulation model. WINNOW results could be entered into such a forest regulation model.

Table 4.—Definitions and equations for use with WINNOW procedures

	Stand Descriptors	
s	= number of species in stand, $i = 1, s$.	
d	= number of size classes, $j = 1, d$.	
m	= smallest merchantable size class, $j = m, d$.	
t	= length of cutting cycle, years.	
$N(t)_{ij}$	= number of trees per unit area (/U) for species i and size class j.	
	Cubic Volume (CV) Units	
CV_{ij}	= CV of tree, species i, size class j.	
$CVT(t)$	$= \sum_{i=1}^{s} \sum_{j=1}^{d} CV_{ij}N(t)_{ij}$ = total stand CV/U, (stand table basis-aggregating).	[1.1]
$CVP(t)_{ij}$	= percent of stand CV/U, species i, size class j	
CV_{ij}	$= [CVT(t) \times CVP(t)_{ij}]/N(t)_{ij}$ = CV of tree (stand volume basis-disaggregating).	[1.2]
$CVH(t)$	$= CVT(t) - CVT(0)$ = CV harvest.	[1.3]
$CVCUTP(t)$	$= CVH(t)/CVT(t)$ = CV percent cut.	[1.4]
$CVPAI(t)$	$= [CVT(t) - CVT(0)]/t$ = CV periodic annual increment,	[1.5a] or
	$= CVH(t)/t$.	[1.5b]
	Merchantable Volume (MV) Units	
MV_{ij}	= MV of tree (board feet, Scribner Rule), species i, size class j.	
$MVT(t)$	$= \sum_{i=1}^{s} \sum_{j=m}^{d} MV_{ij}N(t)_{ij}$ = total stand MV/U, (stand table basis-aggregating).	[2.1]
$MVP(t)_{ij}$	= percent of stand MV/U, species i, size class j.	
MV_{ij}	$= [MVT(t) \times MVP(t)_{ij}]/N(t)_{ij}$ = CV of tree (stand volume basis-disaggregating).	[2.2]
$MVH(t)$	$= MVT(t) - MVT(0)$ = MV harvest.	[2.3]
$MVCUTP(t)$	$= MVH(t)/MVT(t)$ = MV percent cut.	[2.4]
$MVPAI(t)$	$= [MVT(t) - MVT(0)]/t$ = MV periodic annual increment,	[2.5a] or
	$= MVH(t)/t$.	[2.5b]
	Economic Units	
S_{ij}	= present value per unit, volume or tree.	
p	= long term discount rate of organization.	
a	= real stumpage appreciation rate predicted.	
AC	= annual cost/U for administration and protection.	
$R(t)$	$= \sum_{i=1}^{s} \sum_{j=m}^{d} MV_{ij}N(t)_{ij}S_{ij}$ = revenue from merchantable volume	[3.1]
C_b	$= \sum_{i=1}^{s} \sum_{j=m}^{d} MV_{ij}N(0)_{ij}S_{ij}$ = initial value of MV.	[3.2]
C_c	$= \sum_{i=1}^{s} \sum_{j=1}^{m-1} CV_{ij}N(0)_{ij}S_{ij}$ = initial value of sub-MV.	[3.3]
C	$= C_b + C_c$ = initial stand value (invested capital)	[3.4]

Land expectation value (LEV):

$$LEV = \frac{R(t)}{(1+p)^t - 1} - \frac{(1+p)^t - 1] + AC/p\,[(1+p)^t - 1]}{(1+p)^t - 1} \quad [4.1a]$$

$$= \frac{R(t)}{(1+p)^t - 1} - [C + AC/p] \quad [4.1b]^{1,2}$$

LEV with appreciating real stumpage value-

$$LEV = \frac{R(t)}{(1+p)^t/(1+a)^t - 1} - [C + AC/p] \quad [4.2]$$

Annualized LEV or land rent equivalent (LRE):

$$LRE = LEV/p \quad [5]$$

Discount/appreciation factor (simplifies computation of Eq. 4.2):

$$(1+p)^t/(1+a)^t - 1 = d/a \text{ factor.} \quad [6]$$

[1]As 4.1b is formulated, the cost term (second term) is not influenced by cutting cycle length Thus, the optimum prescription can be found from the maximum gross revenue term, i.e., without considering constant costs. The cost term must be included to find land expection value

[2]If p is varied until $LEV = 0$ then p = the internal rate of return

A CASE STUDY

Idaho State land managers, using WINNOW procedures, selected a "best" WINNOW (bW) prescription for some stands in their Southwest Area. This case study illustrates their use of the procedures and results of one bW evaluation.

The setting.—The Idaho Department of Lands has about 70,000 acres (28,330 ha) under all-aged management in their Southwest Area (Cooper 1976). Of special interest are some stands in the Boise Basin near New Centerville, Idaho (fig. 1).

The land type is mature with dissected mountain slopes in a dendritic drainage pattern. Soils are mainly gravelly-sandy-loam or sandy-clay-loam derived from well weathered granite.[5]

[4]See footnote 1.

[5]Unpublished report: Soil-hydrologic reconnaissance survey, 1973; Idaho City Ranger District, Boise National Forest, Idaho City, Idaho.

Slopes range from 20 to 50 percent with generally north to northwest aspects at 4,400 to 4,700 ft (1 340 to 1 430 m) elevation.

With 20 to 25 inches (51 to 64 cm) of rainfall per year, the dry Douglas-fir habitat types (h.t.) (Steele and others 1981) predominate—*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco/*Calamagrostis rubescens* Buckl. (PSME/CARU) (Douglas-fir/pinegrass) h.t. and *Pseudotsuga menziesii/Carex geyerii* Boott (PSME/CAGE) (Douglas-fir/elk sedge) h.t. sp. Fires have periodically burned through these dry forests providing a natural selection of the seral and fire-resistant species ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.).

Ponderosa pine is favored for management over Douglas-fir because it predominates in these stands. Ponderosa pine releases well and has good radial increment on these drier sites.

In this setting, foresters have asked: "What is the best all-aged silvicultural-managerial prescription for these ponderosa pine stands on a Douglas-fir/pinegrass habitat type?"

What is the owner's objective?—Let's first look at the foresters' decision criterion. The Idaho State constitution provides management direction for selecting the "best" prescription. This objective has been interpreted by the Department of Lands as:

> State Forest Lands shall be managed in a manner that will maintain and improve the timber productivity capacity to assure maximum long-term financial returns to the endowment funds. This management goal must be achieved without jeopardizing the other uses of state forested lands for watershed, forage, recreation, wildlife habitat and enjoyment of the aesthetic quality. (Operations Memorandum Number 901, August 1971, Department of Lands, State of Idaho [Cooper 1976]).

"Maximum long-term financial returns" is a clear, concise objective. We interpret the decision criterion to be maximum land expectation value (max LEV) (table 4, eq. 4.1a).

Further, it is generally accepted that real stumpage values are appreciating (Medema and Moore 1980; Hagenstein[6]). We recognize this by including an appreciation rate, *a* (table 4, eq. 6; table 5), in the LEV revenue term (table 4, eq. 4.2).

Then, because volume productivity measures are generally annual rates, let's convert LEV to an annual rate that will not change the relative standing of the trial prescriptions. We will call this the land rent equivalent (LRE) (table 4, eq. 5). Now:

Decision criterion = max LRE.

[6]Hagenstein, Perry. Alternative forest policies for the Pacific Northwest. Manuscript in preparation.

What interest/discount rate should apply?—Economic theory suggests that an alternative rate of return (ROR), *p*, should be established for each organization. Investments not meeting the ROR should be liquidated and the resulting funds reinvested where the ROR will be produced. A recent analysis suggests that 5 percent is a reasonable ROR criterion for the State of Idaho Endowment Fund (Medema and Moore 1980). This represents a 3 percent real rate with a 2 percent risk premium. Then, for $(1 + p)^t$:

$p = 0.05 =$ ROR.

What tree or stumpage values are appropriate?—The values for merchantable volume, by tree size, were based on Department records. Values for smaller trees were derived as a compromise between planted costs, discounted future values, and estimated market values (table 6).

We constrain the decision criterion to meet other State income objectives, insure productivity levels, avoid "jeopardizing the other uses," and recognize State organizational limits and operational (logger) requirements.

What stumpage value appreciation rate should be used?—Medema and Moore (1980) summarized published estimates of increases in real stumpage prices. They found a range of between 3 and 3.5 percent. They used 3 percent in their analysis of management alternatives on Idaho State lands. We will also use a 3 percent annual rate. Then for $(1 + a)^t$:

$a = 0.03$.

Table 6.—Tree and stumpage values used for determining the best WINNOW (bW) prescription

Tree size class		Value
Inches	*cm*	*Dollars*
		per tree
1.0- 4.9	02-12	$ 0.25
5.0- 8.9	13-22	.90
		per MBF
9.0-12.9	23-32	$15.00
13.0-16.9	33-42	35.00
17.0-20.9	43-52	55.00
21.0+	53+	65.00

Table 5.—Revenue discount (*p*)/stumpage appreciation (*a*) factors (F) by cutting cycle (*t*) where: $F = \frac{(1 + p)^t}{(1 + a)^t} - 1$

Discount rate, *p*	Appreciation rate, *a*	Discount/appreciation factor, F for cutting cycle years		
		12	14	16
5	3	0.2596	0.3090	0.3603
6	3	.4113	.4947	.5831
8	3	.7662	.9418	1.1349
10	3	1.2012	1.5106	1.8635

How much are the annual costs?—Area managers provided an estimate of annual costs, AC, to administer and protect these stands:

AC, dollars/acre(/ha) = \$2.60 (\$6.42).

The prescription constraints are based on the five elements of the prescription:

What species composition alternatives should be tried?—These stands were designated to produce only ponderosa pine because of growth and management considerations described earlier:

Species composition = PP@100 percent.

What stand structure (q) alternatives are reasonable?—As "q" decreases so does the relative number of stems in successively smaller size classes (table 2). With "q" = 1.10 there are 10 percent more trees in the next lower size class. This means that as all trees grow and pass to the next size class only one tree in 10 in each size class (except the largest) could die, be culled, or harvested and still maintain a "q" value of 1.10. Our professional judgment suggested this was a minimum "q" for the 2-inch (5-cm) size classes we use. Our trial set was:

q = 1.10, 1.20, 1.30.

What maximum d.b.h. alternatives do we have?—Our concern was for the maximum size trees (d.b.h.) to be left after harvest. Seed production is highly correlated with tree size. We needed to retain trees large enough to provide sufficient seed for natural regeneration of the stand. We estimated that dominant trees 16 inches (40.6 cm) in d.b.h. were the smallest trees to meet this criterion. Our trial set of maximum tree sizes was:

Max d.b.h., inches (cm) = 16, 18 (40.6, 45.7).

What stand densities are reasonable?—Regeneration and juvenile growth were again concerns in selecting the maximum reserve basal area standard. If stands were too dense, germination would be severely limited, seedling mortality high, and juvenile growth slow. Interharvest period also influenced density choices. Longer cycles would start with less dense stands to insure desired growth for the full period. We felt that 65 ft^2/acre (14.9 m^2/ha) of basal area was the maximum density to meet our criterion. Our trial set was:

Basal area density, ft^2/acre (m^2/ha) = 55, 60, 65 (12.6, 13.8, 14.9).

What interharvest periods are reasonable?—Presently, the Southwest Area uses a cutting cycle of 20 years. Staff members felt the organization could handle as short a period as 12 years. They also felt soils would not suffer from this frequent a reentry. Our trial set was:

Interharvest period, years = 12, 14, 16.

Area foresters recognized three special constraints—two on harvesting and one on productivity—as follows:

What limits apply to the volume cut?—Minimum merchantable volume harvest (MVH[t]) and maximum cubic volume harvest (CVH[t]) limits were identified. Some minimum volume must be removed for a logging operation to "break even" or become profitable. Experience suggested that a logger must harvest at least 2 M bd.ft./acre (5 M bd.ft./ha) to have a profitable operation.

On the other hand, removing too much volume would severely impact a stand and reduce growth. Again, experience suggested that no more than 50 percent of total cubic volume, CVT(t), should be removed at one harvest.

Our harvesting constraints were:

Min MVH(t), M bd.ft./acre(/ha) $\geq$ 2 (5)

Max CVH(t), percent $\leq$ 0.50 CVT[t]

Should a productivity limit be set? At what level?—When we started this study we had little knowledge of relationships between volume productivity and value productivity. We knew that support for Idaho schools came from the Endowment Fund but included some income taxes. Thus, maximum funds generated for schools would be some optimum mix of endowment funds and income taxes. We reasoned that maximum stand value yield might be significantly below cubic volume yield potential (max CVPAI), so that sawmill-generated income (and State income taxes) might be less under an optimum prescription. For this reason we set a minimum volume productivity limit based on the maximum productivity (max CVPAI) found in our trial set:

CVPAI(t) $\geq$ 0.90(max CVPAI).

It is appropriate to summarize the number of trial prescriptions (table 7), before considering measurement units.

Table 7.—Summary of trial prescription elements and number of trial projections

Prescription element	Trial levels	Number of trials
Species composition	PP @ 100 percent	1
Stand structure, q	1.10, 1.20, 1.30	3
Maximum tree size, d.b.h., inches (cm)	16, 18 (40.6, 45.7)	2
Stand density, basal area ft^2/acre (m^2/ha)	55, 60, 65 (12.6, 13.8, 14.9)	3
Interharvest period, year	12, 14, 16	[1]1
Number of projections:		(1 × 3 × 2 × 3 × 1 = 18)

[1]One projection with printout at each trial year, that is, 12, 14, and 16.

What measurement units to use?—Measurement units for evaluating the bW prescription generally stem from the decision criterion, the constraints, and units used in growth projection. In our case we used periodic annual increment in cubic volume (CVPAI), merchantable volume (MVPAI), and land rent equivalent (LRE); from cubic volume measures we derived the cut percent—CVH(t)/CVT(t); we set a minimum merchantable volume harvest:

Our measurement units: CVPAI, MVPAI, LRE, CVH(t)/CVT(t), MVH(t).

The decision criterion, constraints, measurement units, and number of projections are summarized on the form shown in figure 2. The growth simulator, GPS, provides data for all but the LRE, which must be calculated by hand.

Data Processing

The data processing procedures have been kept simple. WINNOW and GPS are operational at the Computer Service Center at Washington State University. The center uses an IBM 370 with an AMDAHL V-8 operating system. Experienced programers should have little trouble in modifying WINNOW programs for other installations. We assume users are familiar with GPS (Wykoff and others 1982). The WINNOW programs and computation instructions are available through the senior author of this paper, Dale O. Hall.

Volume Productivity

Volume productivity data are readily summarized from GPS printouts (Wykoff and others 1982). The printout should include at least "Options and Input," "Stand Composition," and "Summary" ("Key Word" = "Summary") tables. "Options and Input" should be carefully checked for prescription accuracy. The "Stand Composition" table is used to find merchantable volume for each species and size class. The "Summary Table" provides net volumes in English units per acre[7] at specified times (t) (table 4, eq. 1.1 and 2.1). These tabulated volumes are used to calculate growth (PAI), harvest, and harvest percent (table 4, eq. 1.3, 1.5, 2.3, and 2.5).

These volume and/or other measures of attainment of objectives or constraints may be summarized for each trial stand and cutting cycle on the "Stand and Land Value Determination" form, shown in figure 3.

The merchantable volume must be distributed by species and size class to obtain reasonable value estimates for stand growth. The GPS "Stand Composition" table provides species and diameter distribution data by number of trees and cubic volume. We convert cubic volume species and size class proportions to similar proportions in merchantable volume.

The number of trees in the two smallest size classes is taken from the WINNOW stand tables (stand file).

Value Productivity

The calculation of value productivity has been greatly simplified. We assume that cycle length does not vary, revenues are the same at each future cut, and harvest returns the stand to initial condition and value. We use present values in calculating initial stand investment value and the future revenue for each cutting cycle—the discount/appreciation (d/a) factor will account for trends in future values (table 4, eq. 6 and 4.2; table 5).

Stand investment value is the sum of all size class values per unit area for all species, at time t, $t = 0$ (fig. 3, col. 7). Stand revenue at t is the sum of **merchantable** size class values per unit area for all species using the **present** values per thousand board feet.

In the Idaho case study we had only one d/a combination. We calculated the d/a factor for the three trial interharvest periods and made a simple table (table 5, line 1).

The end-of-period revenue divided by the appropriate d/a factor gives the present value of an infinite series of like revenues.

Total cost in this formulation (table 4, eq. 4.1b) is the sum of initial stand investment value, C, and equal annual costs accumulated and discounted to the present, AC/p.

LEV (table 4, eq. 4.1) is the algebraic sum of total cost and gross value of accumulated revenues. LEV is the estimated value of the specified land (bare) for growing an infinite series of like tree crops under the assumptions of the prescription, the growth model, and the economic evaluation model.

Comparing LEV's, or their transforms, LRE's (table 4, eq. 5), will show the relative economic productivity of different prescriptions for the same site, of different sites, and of different forms of management: even-aged (Larsen 1977) and all-aged (Hall[8]).

Winnowing Prescriptions

In our case study, we projected the 18 trial prescriptions (table 7) with GPS specifying summary prints at 12, 14, and 16 years (the three cutting cycles), made the 54 economic evaluations, and tabulated the results (table 8).

Our constraints served two purposes: to limit the number of trial prescriptions, and to limit the number of "acceptable" projections. An acceptable projection has met all constraints and will be tested against the objective or decision criterion.

Winnowing the volume productivity results through our constraints we find that:

max CVPAI = 117 ft^3/acre/yr (8.19 m^3/ha/yr)
Prescription: PP100–1.20–16–65–12;
(PP100–1.20–40.6–14.9–12)

hence:

min CVPAI(t) $\geq 0.90 \times 117 = 105$ ft^3/acre/yr or
min CVPAI(t) $\geq 0.90 \times 8.19 = 7.37$ m^3/ha/yr (use 7.35 m^3/ha/yr).

Prescriptions producing less than the minimum acceptable CVPAI are "chaff" (shaded values in table 8).

Continuing the winnowing process we find that our harvest limit,

max CVH(t) $\leq$ 0.50 CVT (t),

eliminates all but one prescription with a 16-year cutting cycle and all but four with 14-year cycles. All prescriptions with 12-year cycles meet the constraint. Prescriptions not meeting harvest limits are shown with hatched lines (table 8).[9]

[7]Conversion factors we used for metric units are:
m^3/ha = 0.0700 ft^3/acre
m^3, merchantable = 424 bd.ft.
m^2/ha = 0.2296 ft^2/acre

[8]See footnote 1.

[9]Had efficiency in using the procedure been one of our study objectives, we could have foregone economic evaluation for 40 of the 54 trial prescriptions based on their failure to meet two volume constraints—(CVPAI[t]) $\geq$ (0.90 Max CVPAI), and CVH(t) $\leq$ (0.50 CVT[t])—the shaded and hatched portions of table 8. We made the 54 economic evaluations to see more clearly the value relationships between prescription elements and to allow comparisons when different objectives and constraint sets were used.

Form .—Stand and Land Value Determination. Unit IDL-DF/CARU ; Planner Hall and Bruna: 4/4/81 Q311065
(1) Stand ID

(2) Inter-harvest period (yr), t = 0

(8)

	t = 12	t = 14	t = 16
PAI · CF =	114 H^3/ACRE	112	110
PAI · BF =	473 b.f./ACRE	473	470
CF Cut Pct =	.46	.49	.52

(3) Tree Value-Size Classes (in)	(cm)	(4) Part of Total Volume (pct)	(5) Quantity Per Unit Area (nbr/mbf)	(6) Value/ Unit Quantity (dollars)	(7) Value Per Unit Area (dollars)	t = 12 Part of Total Volume (pct)	Quantity Per Acre (mbf)	Value Per Acre ($)	t = 14 Part of Total Volume (pct)	Quantity Per Acre (mbf)	Value Per Acre ($)	t = 16 Part of Total Volume (pct)	Quantity Per Acre (mbf)	Value Per Acre ($)
SPECIES PONDEROSA PINE - 100%														
1.0- 4.9	02-12		51.4	$0.25	$12.85									
5.0- 8.9	13-22		42.5	0.90	38.25									
9.0-12.9	23-32	.66	2.981	15.00	44.72	.18	0.997	14.96	.15	1.018	15.27	.11	0.827	12.41
13.0-16.9	33-42	.34	1.565	35.00	54.78	.33	1.870	65.43	.33	2.181	76.33	.39	2.932	102.62
17.0-20.9	43-52	—	—	55.00	—	.48	2.742	150.81	.43	2.835	155.93	.44	3.308	181.94
21.0 +	53 +	—	—	65.00	—	.01	0.062	4.05	.09	0.581	37.80	.06	0.451	29.32
SPECIES NONE														
1.0- 4.9	02-12													
5.0- 8.9	13-22													
9.0-12.9	23-32													
13.0-16.9	33-42													
17.0-20.9	43-52													
21.0 +	53 +													
		1.00	4.546	Stand Invest't	$150.59	1.00	5.671	235.25 Revenue	1.00	6.615	285.32 Revenue	1.00	7.518	326.29 Revenue

(9) Int Rate, i	(10) Appr Rate, a	(11) Accum Ann Cost	(12) Total Cost	(13) Dsct/ Appr/ Factor	(14) Gross Value Reven's	(15) Land Exp'tn Value	(16) Annual Rent Equiv't	Dsct/ Appr Factor	Gross Value Reven's	Land Exp'tn Value	Annual Rent Equiv't	Dsct/ Appr Factor	Gross Value Reven's	Land Exp'tn Value	Annual Rent Equiv't
1.05	1.03	52.00	202.59	.2596	906.21	703.62	35.20	.3090	923.37	720.78	36.05	.3603	906.61	703.02	35.15
1.08	1.03	32.50	183.09	.7662	307.07	123.98	9.92	.9418	302.95	119.86	9.59	1.1349	287.81	104.48	8.35

INT-1208-D011 Ver 1.1 (4/81) NOTE: COLUMN TOTALS MAY NOT SUM EXACTLY DUE TO ROUNDING.

Figure 3.—Stand and land value determination form for bW prescription.

Table 8.—Comparative simulated yields from alternative all-aged prescriptions for a Douglas-fir/pinegrass-ponderosa pine habitat typ
in central Idaho

Prescription Elements, 1–5			Periodic Annual Increment											
(1) Species composition: PP@100 percent			Land rent equivalent			Merchantable volume			Cubic volume			Portion periodic cubic volume harvested		
			(5) CUTTING CYCLE, YEARS											
(2) "q"	(3) Max d.b.h.	(4) Res stkg.	12	14	16	12	14	16	12	14	16	12	14	16
			Per acre per year											
	Inches	*Ft²*	*Dollars*			*Board feet*			*Cubic feet*			*Percent*		
1.10	16	55	32.35	32.85	33.30	430	431	431	103	102	101	48	51	54
		60	34.05	34.85	34.50	453	454	452	109	107	106	47	50	53
		65	35.20	36.05	35.15	473	473	470	114	112	110	46	49	52
	18	55	29.90	30.75	30.70	377	377	381	94	93	92	43	47	50
		60	32.15	32.30	32.30	399	398	401	100	99	97	42	46	49
		65	33.10	32.60	32.05	416	414	417	105	103	101	42	45	48
1.20	16	59	30.35	31.75	30.75	423	425	425	106	105	104	49	53	56
		60	32.30	33.00	32.25	449	450	449	112	111	109	49	52	55
		65	31.90	32.45	31.55	468	468	467	117	115	114	48	51	54
	18	55	27.95	28.45	28.70	384	383	387	99	98	97	45	49	52
		60	29.15	29.80	29.90	405	404	406	104	103	101	45	48	51
		65	31.55	30.30	30.45	441	420	422	109	107	105	44	47	50
1.30	16	55	23.45	24.40		377	383	390	101	101	102	49	53	56
		60	24.30	25.20		397	402	408	106	105	105	48	52	55
		65	25.10	25.65		417	418	423	110	109	109	47	50	54
	18	55	23.20	23.20		348	347	359	96	95	95	45	49	52
		60	23.85	23.95		364	362	373	100	99	99	44	45	51
		65	24.15	25.05		378	380	384	104	103	102	43	47	50
			Per hectare per year											
	cm	*m²*	*Dollars*			*Board feet*			*Cubic meters*			*Percent*		
1.10	40.6	12.6	79.95	81.15	82.30	1063	1065	1065	7.21	7.14	7.07	48	51	54
		13.8	84.15	86.10	85.25	1119	1122	1117	7.63	7.49	7.42	47	50	53
		14.9	87.00	89.10	86.85	1169	1169	1161	7.98	7.84	7.70	46	49	52
	45.7	12.6	73.90	76.00	75.85	932	932	941	6.58	6.51	6.44	43	47	50
		13.8	79.45	79.80	79.80	986	983	991	7.00	6.93	6.79	42	46	49
		14.9	81.80	80.55	79.20	1028	1023	1030	7.35	7.21	7.07	42	45	48
1.20	40.6	12.6	75.00	78.45	76.00	1045	1050	1050	7.42	7.35	7.28	49	53	56
		13.8	79.80	81.55	79.70	1109	1112	1109	7.84	7.77	7.63	49	52	55
		14.9	78.80	80.15	77.95	1156	1156	1154	8.19	8.05	7.98	48	51	54
	45.7	12.6	69.05	70.30	70.90	949	946	956	6.93	6.86	6.79	45	49	52
		13.8	72.05	73.65	73.90	1001	998	1003	7.28	7.21	7.07	45	48	51
		14.9	77.95	74.85	75.25	1090	1038	1043	7.63	7.49	7.35	44	47	50
1.30	40.6	12.6	57.95	60.30		932	946	964	7.07	7.07	7.14	49	53	56
		13.8	60.05	62.25		981	993	1008	7.42	7.35	7.35	48	52	55
		14.9	62.00	63.40		1030	1033	1045	7.70	7.63	7.63	47	50	54
	45.7	12.6	57.35	57.35		860	857	887	6.72	6.65	6.65	45	49	52
		13.8	58.95	59.20		899	894	922	7.00	6.93	6.93	44	48	51
		14.9	59.65	61.90		934	939	949	7.28	7.21	7.14	43	47	50

Note: Shaded values do not meet productivity constraint = 0.90 × (cubic volume yield potential). Hatched values fail the harvest constraint = 0.50 × (stand cubic volume).

Our board-foot harvest constraint,

MVH(t) $\geq$ 2 m.b.f./acre (5 m.b.f./ha),

was not operational; that is, all board-foot harvests were at least twice the established limit.

The last comparison was against the decision criterion, the "test of best":

max LRE = bW prescription.

The tentative bW prescription was:

PP100–1.10–16–65–14 (table 9)
(PP100–1.10–40.6–14.9–14).

Table 9.—Size distribution and characteristics of the best WINNOW prescription for Douglas-fir/pinegrass-ponderosa pine habitat type, central Idaho

DBH		Stems per acre	Stems per hectare
Inches	*cm*		
4	10.2	22.0	54.36
6	15.2	20.0	49.42
8	20.3	18.2	44.97
10	25.4	16.4	40.52
12	30.5	15.0	37.07
14	35.6	13.7	33.85
16	40.6	12.4	30.64
Total		118	290.83

Mean D = 10.1 (25.7)
Stand density index: trees/acre(/ha) = 120 (300)

Note: The prescription is
species composition = 100 percent ponderosa pine
stand structure, "q" = 1.10
reserve stocking, basal area = 65 ft^2/acre (14.9 m^2/ha)
maximum reserve tree size, d.b.h. = 16 inches (40.6 cm)
cutting cycle = 14 years.

Proving the Best

On selection of one of the trial prescriptions, the question of refining the prescription comes up. In our example the only prescription element that could change our choice of bW, within our constraint framework, is the cutting cycle; 13- or 15-year cycles might produce a greater LRE. Because of the indicated relationships we felt that the 14-year cycle was best.

Our selection was still tentative. We asked ourselves:

1. Does the GPS projection seem realistic in view of our knowledge base?
2. Are our economic evaluations reasonable expectations?
3. Will these prescription elements fully meet our constraints?
4. Have we included **all** the necessary constraints for these stands...biologic, economic, sociologic?

In effect, we now knew what the prescription and stand looked like (table 9). We reversed our perspective and asked, did it fully meet the objective and constraints, and was it realistic? We also sought independent opinions from other foresters. When we found no serious criticism, we finally accepted it as our bW prescription.

Applying the bW Prescription

Implementation of the bW prescription requires carefully considering other questions before application:

1. What steps should be taken to move the stand from its present condition to the desired prescription? What time frame?
2. What are the site limits for applying the prescription?
3. How are individual trees selected to avoid undesirable alterations to the gene pool?
4. Are all **age** classes present or have smaller trees just been less vigorous?
5. What relative size/spacing standard should be used?

COSTS AND RETURNS FOR bW ALTERNATIVE USE PRESCRIPTIONS

The estimated relationships between different prescriptions and stand potentials are enlightening. Some managers advocate producing the maximum cubic volume (max CVPAI). They may make such advocacy without appreciating the cost of their actions (table 10, a and b). The objective of maximum cubic volume production shows an annual cost (reduction in LRE) of \$4.96/acre (\$10.30/ha) for a gain of 5 ft^3/acre (35 m^3/ha) in volume over the prescription which maximizes LRE. Obtaining the last 4 percent in potential volume carries a high cost—14 percent of stand value every year.

Resource values other than timber may be compared in this framework. Consider an alternative constraint to increase water yield; stand density to be 55 ft^2/acre (12.6 m^2/ha) in basal area. This 15 percent reduction in stand density (basal area) over a watershed should increase water yields by 0.5 inch (1.3 cm). The irrigation value of water in central Idaho in 1980 was about \$25/acre foot (\$2.024/100 m^3) (personal communication, Joe Rabb, Boise, Idaho, November 1980). Assuming no significant loss in volume during transport, the extra water yield (value of \$1.04/acre or \$2.57/ha) had a net **cost** to the watershed each year of \$4.66/acre (\$1:.85/ha) (table 10, a and c).

Wildlife resource values, as described earlier, may also be compared. Assume that about 100 trees, 1 to 4 inches d.b.h./acre (250 trees, 2 to 12 cm d.b.h./ha) will provide the required deer and elk hiding cover (Thomas and others 1979) in a stand. A "q" value of 1.30 with 65 ft^2/acre (14.9 m^2/ha) basal area will provide this many small trees (table 2) so we set our big game hiding cover constraint as: q $\geq$ 1.30. We then compare with the best timber prescription (table 10, a and d). The prescription insuring deer and elk hiding cover will yield \$10.40/acre (\$25.70/ha) less each year than would the best timber prescription.

SUMMARY AND CONCLUSIONS

We have examined the problem of selecting the best silvicultural/managerial prescription for an all-aged stand. The two phases of the problem are projecting growth and selecting the optimum prescription. Although any growth projection method could be used, we interface with Stage's (1973) growth prognosis system (GPS). We use Hall's[10] iterative WINNOW procedures to select the best prescription for a stand on State of Idaho lands.

Stands are described by five parameters: species composition, stand structure (''q''), maximum reserve tree size (d.b.h.), stand density (basal area), and interharvest period. We vary these parameters and examine 54 alternative prescriptions. The WINNOW programs efficiently and quickly map many stand prescriptions to tree records and stand files and then interface stand files with GPS to estimate volume growth and yields. A simple calculation procedure provides estimates of economic productivity in terms of land expectation value (LEV) and annual land rent equivalent (LRE).

[10]See footnote 1.

The numerous estimated volume and value yields are ''winnowed'' through prespecified silvicultural and managerial constraints. The remaining prescriptions are compared against the owner's ''test of best'' to pick one best WINNOW (bW) prescription. Finally, the selected prescription is examined carefully, in the light of all available experience with the stand, testing for silvicultural and managerial realism and consistency. When accepted, the bW prescription becomes the goal toward which the stand should be moved. Potential yields and values constrained for different resource needs may be readily compared with maximum timber productivity.

The methods and procedures described are relatively simple to use. Once growth projections are in hand, the sophisticated economic evaluations take a few simple desk calculations.

Application of bW prescriptions should generally increase volume and/or value yields. In our case study stand in Idaho, we compared the bW prescription against a 12-year no-treatment projection (table 10, a and e). The bW prescription showed an estimated 30 percent increase in cubic volume yield, a 100 percent increase in merchantable volume yield, and a 400 percent increase in value productivity. The stand manager scheduled early treatment to move the stand toward the bW prescription.

Table 10.—Relative productivity estimates for best WINNOW prescriptions to meet five different management objectives and constraint sets for Douglas-fir/pinegrass-ponderosa pine habitat type, central Idaho

Prescription elements	a) Maximum LRE, timber	b) Maximum cubic vol., PAI, timber	c) Maximum LRE, timber and water[1]	d) Maximum LRE, timber and hiding cover	e) No treatment
	Management objective				
	Best WINNOW prescription				
Species composition, percent b.a.	1.00	1.00	1.00	1.00	1.00
Stand structure, "q"	1.10	1.20	1.10	1.30	1.70
Maximum tree size, d.b.h., inches (cm)	16 (40.6)	16 (40.6)	16 (40.6)	16 (40.6)	26 (66.0)
Reserve stocking, b.a., ft²/acre (m²/ha)	65 (14.9)	65 (14.9)	55 (12.6)	65 (14.9)	136 (31.1)
Cutting cycle, year	14	12	12	14	12
	Estimated annual growth for prescription[2]				
Value (annual rent), $/acre ($/ha)	36.05 (89.10)	31.55 (78.80)	31.39 (77.57)	25.65 (63.40)	7.90 (19.52)
Merchantable volume, b.f./acre (b.f./ha)	473 (1169)	441 (1156)	423 (1045)	418 (1033)	230 (568)
Cubic volume, ft³/acre (m³/ha)	112 (7.84)	117 (8.19)	106 (7.42)	109 (7.63)	85 (5.95)
Basal area, ft²/acre (m²/ha)	2.3 (0.53)	2.6 (0.60)	2.3 (0.53)	2.6 (0.60)	2.4 (0.55)
Quadratic mean diameter, inches (cm)	0.176 (0.447)	0.208 (0.528)	0.217 (0.550)	0.200 (0.508)	0.050 (0.127)
Rings per inch (cm)	11.4 (4.5)	9.6 (3.8)	9.2 (3.6)	10.0 (3.9)	40 (15.7)

[1]Water valued at $25/acre foot ($2.024/100m³) with a 0.5 inch/acre (1.3cm/ha) increase in water yield.
[2]All but value growth estimates from Stage's (1973) growth prognosis model adjusted with growth plot data provided by Southwest Area, Department of Lands, Boise, Idaho.

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The relatively simple set of WINNOW procedures and computer programs for simulating and selecting one best silvicultural/managerial all-aged prescription from many alternatives is described. The selection basis may be sustained annual volume or value productivity measures. An economic case study evaluates constrained prescription alternatives for a stand of ponderosa pine on a Douglas-fir/pinegrass habitat type in central Idaho. Maximum land (soil) expectation value, based on a new formula for all-aged stands, is the decision criterion. The selected prescription shows potential increases in cubic volume productivity of 30 percent, in merchantable productivity 100 percent, and in value productivity 400 percent. Trade-offs for prescriptions with increased water yield or increased big game hiding cover are compared.

KEYWORDS: soil expection value, uneven-aged stand management, stand prescriptions

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Summarizing Weather and Climatic Data—A Guide for Wildland Managers

Arnold I. Finklin

THE AUTHOR

ARNOLD I. FINKLIN is a meteorologist at the Northern Forest Fire Laboratory, Missoula, Mont. Specializing in climatology, he is currently with the Fire Effects and Use Research and Development Program. Previous assignments at this location were with Project Skyfire and the Fire in Multiple Use Research, Development, and Application Program. He received a bachelor's degree in meteorology at New York University, worked as a research aide at the University of Chicago, and received a master's degree in atmospheric science from Colorado State University before joining the laboratory in 1967.

RESEARCH SUMMARY

This publication is a guide to the summarization of available fire-weather and climatic data by wildland managers, particularly for use in fire-management planning. The publication also covers general needs of forestry research. Various elements are discussed in an outline corresponding to a suggested report format; the format covers both the annual regime and the fire season. Examples are given for presenting the summarized data, including averages and frequency distributions in tables obtained through available computer programs. Graphs that can condense much of the information are also shown. Methods for adjusting or extrapolating values from limited data bases are included in a final section.

CONTENTS

Summarizing Weather and Climatic Data—A Guide for Wildland Managers

Arnold I. Finklin

INTRODUCTION

Weather and climatic data have long been important in the management and protection of our Nation's forests, particularly in the process of fire suppression or control. Use of such information has broadened in recent years under the new concept of fire management (Fischer 1978). Practice of this concept, which recognizes the natural role of fire in wildland ecosystems, considers a variety of resource management objectives.

Weather and climatic data are thus helpful in the planning of prescribed fires—for example, in establishing seasonal limits—and in evaluating the effects of fires, prescribed or wild, on particular resources. These effects may be strongly influenced by the weather, relative to "normal," during the ensuing months or years. The data can provide a baseline (of average or most likely weather conditions), together with a record of past deviations. Other applications, besides those related to fire, include planning for insect control, tree planting, road or trail construction and maintenance, recreational activities, environmental assessment reports or impact statements, and assessment of water supply potential for irrigation.

The purpose of this publication is to aid managers of forest and rangeland resources in their use of the available climatic data.[1] Our scope provides also for general needs of related research.

Emphasis is on evaluating and describing the climate of a particular location or area. Methods are presented for summarizing and presenting the data in tables, graphs, and possibly maps, together with guidance for interpretations and extrapolations. A more extensive discussion of data treatment methods can be obtained from Conrad and Pollak (1962); Oliver (1973).

ACQUISITION AND PROCESSING OF DATA

Climatic Data Requirements; Sources

The elements included in a climatic summary or description will vary, depending on the intended use as well as availability of data. Similarly, the time scale or resolution will vary. Contributing data may be from one or more observing stations representing an area. Interpolations or extrapolations may be made for other locations.

Table 1 outlines the suggested elements or items for a climatic description. Letter symbols, referring to primary data sources, denote inclusion in the specified time frame. Fuel moisture and fire-danger indices, which may be of more ultimate interest in fire management, are not included in our scope.

Much of the data base for the fire or land manager's needs may be obtained from fire-weather observations. These observations include the afternoon temperature, relative humidity, wind, 24-hour precipitation amount and lightning occurrence, and also the 24-hour maximum and minimum temperatures at many stations.[2] Such data have been archived in AFFIRMS (Administrative and Forest Fire Information Retrieval and Management System) format on tapes at the National Fire Weather Data Library, Fort Collins, Colo. (Furman and Brink 1975). They are available through offices that have access to the USDA computer at the Fort Collins Computer Center. Records thus obtained date back to 1954 for some stations (in Idaho, Montana, and Washington); to 1960–65 or later for most. Fire-weather data for additional stations and years may be located on original or carbon-copy forms. For example, those for Forest Service Region 1 stations are on file through 1970 at the Northern Forest Fire Laboratory (NFFL), Missoula, Mont.

For further areal coverage and year-round climatic information, data published by the U.S. Weather Bureau and its successor agencies are available in many libraries or from the National Climatic Center, Federal Building, Asheville, NC 28801. The data are limited mostly to valley or relatively low-elevation locations.

Greatest detail may be obtained from monthly and annual "Climatological Data," State summaries. These include the network of "cooperative" stations, some of which are also fire-weather stations (located at ranger stations). Contents include daily precipitation and maximum and minimum temperatures at each station, plus evaporation data and soil temperatures at a few locations; monthly windspeed, relative humidity, and sunshine data were given for airport stations, before 1982. Also

[1]The term climatic data will include weather data—the daily observations that become the material for climatic statistics.

[2]The 24-hour maximum and minimum relative humidity may also be available, but these data, obtained from hygrothermographs, are subject to large errors. The errors may tend to cancel over a period of years.

Table 1.—Suggested elements and time scales in climatic summaries. Letter symbols refer to data sources described at end of table. Dotted line defines items (generally to left) pertaining to fire-management planning

Element	Time scale: 10-day (Fire season only)	Time scale: Monthly (Fire season only)	Time scale: Monthly (12 months)	Time scale: Annual (12 months)
	Source of data			
Precipitation, amount	F	F	C	C, Sa
number of days	F	F,C	C	C
Snowfall, amount			C	C
Snow cover, duration (days)				
and depth		C	C	C
snowpack		S	S	
Runoff			G	G
Thunderstorms, number of days	F	F,Ce		Be,Ce
Temperature, mean (24-hour)			C	C
daily maximum	F	F	C	
daily minimum	F	F	C	
afternoon dry bulb	F	F		
Freezing temperature				
threshold dates				C
Relative humidity,				
afternoon	F	F	Ae,Ce	
nighttime and 24-hour		Ae,Ce,F	Ae,Ce	
Dewpoint, afternoon	F	F		
Wind, afternoon		F	Ce	
nighttime		Ce		
24-hour			Ae,Ce	
Sunshine, number of hours		Ae	Ae	Ae,Be
percent of maximum possible		Ae,Ce	Ae,Ce	
Solar radiation			Ae, CNe	
Evaporation; potential				
evapotranspiration			Ae,Ce,T	Ae,Ce,T

F Fire-weather observations.
C Various climatological data publications by National Oceanic and Atmospheric Administration (formerly U.S. Weather Bureau) for individual States or stations.
CN Publication as above, except in form of national summary; data discontinued after 1976.
A Climatic Atlas of the United States (Environmental Sciences Service Administration 1968).
B Baldwin (1973).
S Snow survey data, published in monthly Water Supply Outlook and in Summary of Snow Survey Measurements (updated every 5 years); available for 11 western States from USDA Soil Conservation Service (SCS), Portland, OR 97209, and for California from California Department of Water Resources, Sacramento.
G Water-supply bulletins published by U.S. Geological Survey, Reston, VA 22092; later information available from State offices.
a Annual precipitation may be estimated from April 1 snowpack water content using method and graphs of Farnes (1971).
e Data are from airport or widely spaced stations.
T Thornthwaite Associates (1964).

published are "Local Climatological Data" (mostly for airport stations) and "Climatological Data, National Summary." The years of data have been summarized in several "Climatographies of the United States" (U.S. Weather Bureau 1932–37, 1954–58, 1964–65; National Oceanic and Atmospheric Administration [NOAA] 1971). Precipitation data for remote high-elevation locations were published annually in "Storage Gage Precipitation Data for Western United States," discontinued in 1976.

Additional summaries or special field data may be available from other agencies or from universities; for example, Pacific Northwest River Basins Committee (PNWRBC) (1968). A broader-scale picture, in map form, is provided by Environmental Science Services Administration (ESSA) (1968). The data sources are described more thoroughly by ESSA (1969) and Haines (1977); also, for the Columbia Basin States, by Columbia Basin Inter-Agency Committee (1965).

A future store of 24-hour fire-weather data may be provided by recently established remote automatic weather stations (RAWS) (Warren and Vance 1981); these are now installed at about 100 locations in the western United States.

Treatment and Processing of Data

DATA QUALITY CONSIDERATIONS

Errors and Missing Data

Before the acquired data are treated further, they should, ideally, be checked for errors and missing values. Corrections and estimates can then be made. Details are given in the final section of this report. In a search at the Northern Forest Fire Laboratory, many large and noncompensating errors were found in the fire-weather tape for the Forest Service Region 1 stations. There were, for example, some spurious 0 or 1 percent relative humidity values and rainfall amounts 10 to 100 times too high or low. Such errors arose largely in the processing of the original data.

Homogeneity of Data; Station Selection

A complicating factor in the use of climatic data can be change in location or exposure during a station's period of record. This commonly occurs in the network of "cooperative" stations. Even within small distances and elevational differences, such change can significantly affect the climatic averages. A change in daily observation time can be equally disruptive (see final section). In statistical terminology, the data series is no longer "homogeneous," or a sample of a single population (Oliver 1973). The effect may not be serious if the averages are intended only as a general indicator of the seasonal patterns rather than present truth for a specific location. Nonhomogeneity, however, can cause incorrect assessment of a current month's departure from normal conditions. For this purpose, in the case of cooperative stations, it may be safer to use an index that averages the data from a number of stations in or near a particular area. The odds are that inconsistencies at the individual stations will tend to compensate.

In the use of fire-weather data, major changes in afternoon observation time should be known; the record of time-affected elements, such as temperature and relative humidity, split accordingly. The statistics can then be adjusted, as described in the final section, to be compatible with present-day application.

SUMMARIZATION OF DATA; NORMALS

Tables summarizing fire-weather data can be obtained by computer programs (Bradshaw 1981) that are available at the Fort Collins Computer Center. These programs are similar to those used for the examples in the appendix and written by Louis T. Egging and Toni D. Rudolph at the Northern Forest Fire Laboratory. Output includes average and extreme values, as well as frequencies of specific values of weather elements, singly and in combination. These frequencies, if based on enough years of record, may be regarded as probabilities of future occurrence.

The tabular information may be condensed into graphs. Examples shown in this guide were drawn manually, but future computer programing may do the job. Aside from their more vivid portrayal and possibly easier use, the graphs can, when smoothed, help overcome accidental irregularities in tables attempting small time-scale (10-day) resolution. Such irregularities can be expected particularly when the number of years of data is small. The use of smoothing is widely practiced in treating climatic data. Various methods or formulas are given, for example, by Conrad and Pollak (1962); Panofsky and Brier (1963). A balance is sought that reduces accidental irregularities in a data sample while not obscuring characteristics that may be real. The smoothing suggested in this guide is apparently less than that used by NOAA (1973b).

Outside the fire season and for additional stations, only the averages and extreme values may be readily obtainable. Frequency distributions are included in PNWRBC (1968). A most recent general climatography issued by NOAA (1982) lists the average monthly temperatures and precipitation for those stations with a record covering the 30 years, 1951–1980. By international convention, this span of 30 years is the current standard "normal" period; the normals are updated every 10 years. A previous publication (NOAA 1973a) listed the 1941–1970 normals.[3] U.S. Weather Bureau (1964–65) gave averages for shorter periods, as well as the normals then based on 1931–60. Averages for additional stations can be calculated using tabulations from "Climatological Data," State summaries.

Length of Record

As just mentioned, the standard normal period covers 30 years. This length tends to balance out fluctuations over shorter periods; stability of the averages (and frequency distributions) and comparability among stations are sought. A longer period of record is actually desirable for precipitation, which can show large decade-to-decade (besides year-to-year) variation (World Meteorological Organization 1967); example, figure 1. A 20-year data sample, however, particularly with smoothing, should generally be adequate for 10-day averages and frequency distributions of the fire-season temperature, relative humidity, and wind. We would advise against only a 10-year sample (see fig. 2). Lengths of record provided by the fire-weather tapes may possibly be extended to the desired number of years if older observation forms are obtainable. For monthly averages, 10 to 15 years should generally provide accuracy, relative to a 30-year period, within $\pm 1°$ or $2°$ F ($\pm 1°$ C) for temperature and ± 1 or 2 percent for relative humidity. (This is indicated from tabulations by the author of average maximum temperatures at stations in 24 States.)

Where possible, the same specific years should be represented at all stations included in a climatic summary. The averages from stations having short records can be adjusted with good approximation to a common period, such as 20 or 30 years. This adjustment uses the "difference" and "ratio" methods detailed in the final section.

[3]No details were given as to average daily maximum and minimum temperatures. These were shown for "first-order" (mostly airport) stations in NOAA (1973b).

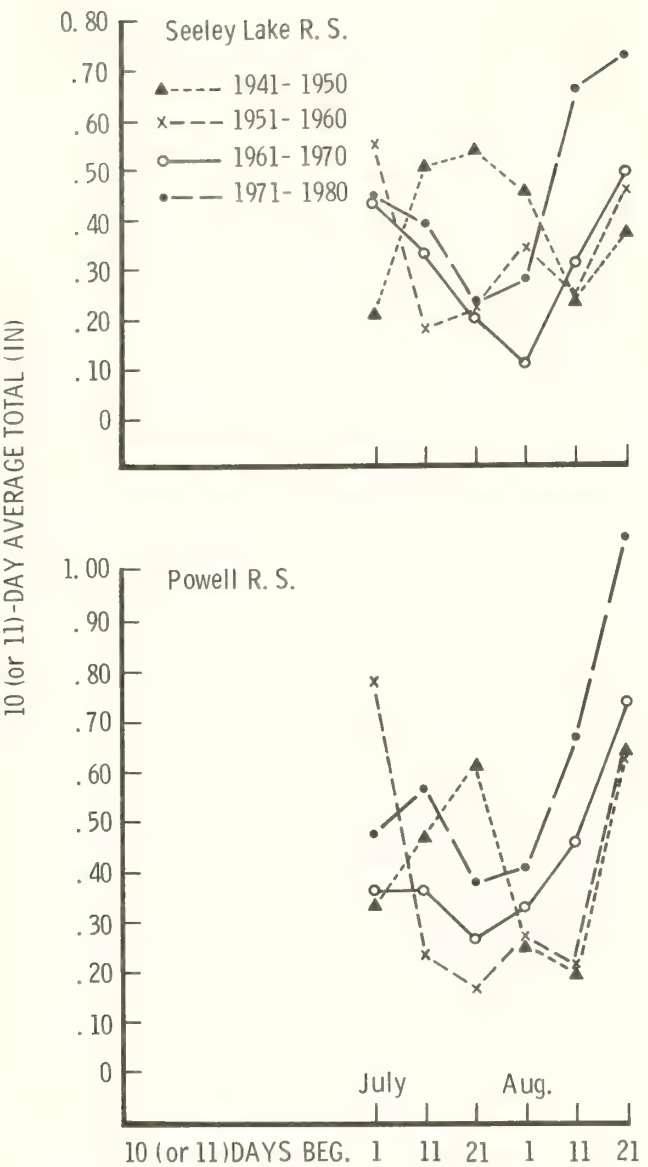


Figure 1.—Ten-day average rainfall during individual 10-year periods at Powell Ranger Station, Idaho, and Seeley Lake Ranger Station, Montana, July and August 1941–80.

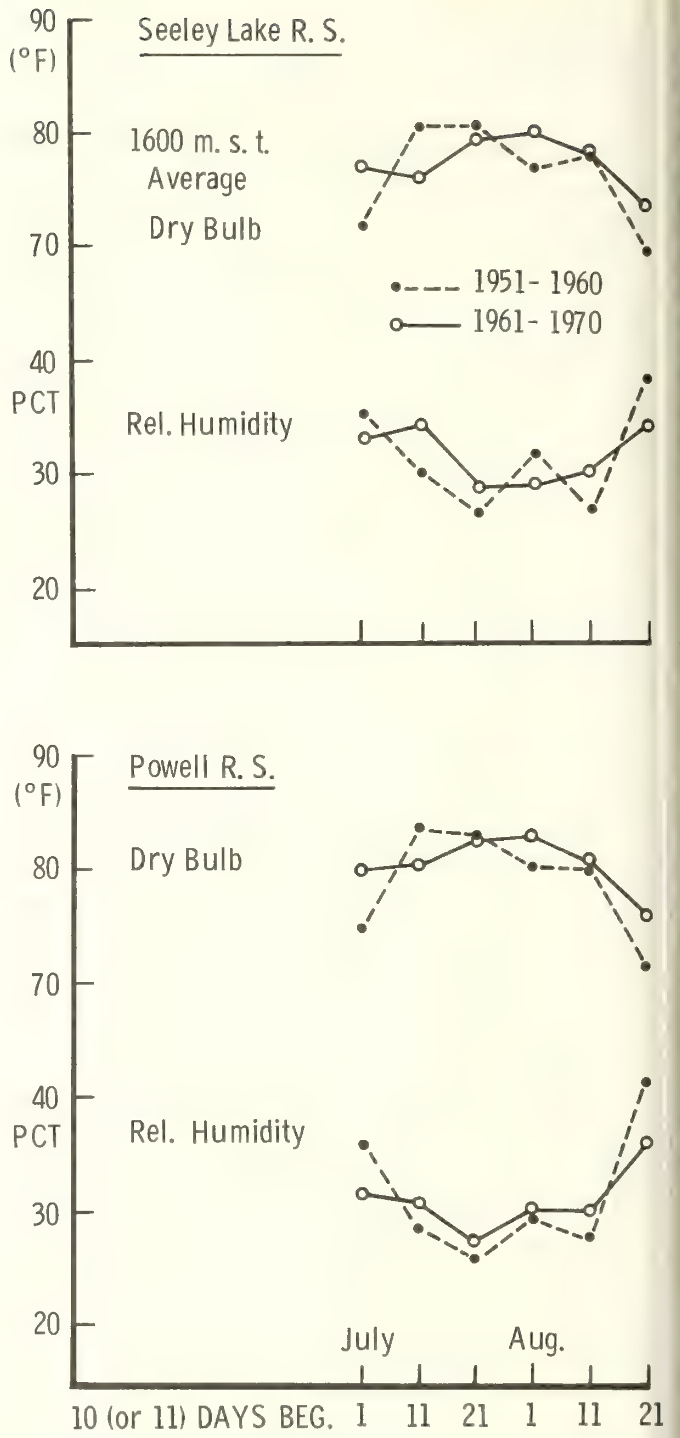


Figure 2.—Ten-day average dry bulb and relative humidity at 1500 P.s.t. (1600 m.s.t.) during two successive 10-year periods at Powell Ranger Station, Idaho, and Seeley Lake Ranger Station, Montana, July and August 1951–70.

PRESENTATION OF THE SUMMARIZED DATA; FORMAT

When the summarized data are presented in report form, the arrangement or sequence will vary, of course, with the individual perspective. A suggested format is given within the following outline of climatic items. Examples of this format can be found in Finklin (1983) and in an office report.[4] Examples of summary tables, graphs, and maps in this outline are mostly from these two references.

The suggested format begins with a general description of the area. Climatic information may be better interpreted if users can visualize the area's physical setting. A basic description is aided by a large-scale map showing the area's location and by a more detailed closeup map depicting the topography. Sufficient detail may be obtained from a map in the U.S. Army Topographic Command Series (fig. 3), available from the U.S. Geological Survey, Denver, CO 80225, or Reston, VA 22092. The user may also be aided by information as to: direction and straight-line distance from a familiar reference place, size and general shape of the area, terrain features including highest and lowest elevations and their locations, drainages, land ownership, habitat types, and general use.

Condensed Climatic Summary

This overview lends itself to use in management (and research) plans, including statements concerned with environmental assessment. The summary, in perhaps 500 words, condenses material from the climatic description that follows; it may actually be easier to write afterward. Suggested subheadings include Precipitation, Thunderstorms, Temperature, Humidity, and Wind.

Details of the Climate

In the present outline, climatic items are discussed first in terms of annual regimes—for example, monthly courses of average temperature and precipitation. The annual picture serves as a framework in which the fire-season climatic details can be presented. Our discussion pertaining to the fire season is given under a separate heading. In an actual report, for greater convenience to users, the annual regime and the fire-season climate may be described in separate main sections.

The fire-season climatic details are generally given with 10-day resolution. This season, that of the fire-weather observations, should include the main periods of wildfire occurrence and prescribed burning. The observation season at lookouts, however, tends to be much shorter than at ranger stations. In the Northern Rockies, for example, the observations are often limited to July and August at lookouts while extending 6 months (May through October) at many ranger stations. Methods of estimating details for the longer season, at least at other canyon or valley locations, are given in the final section of this report.

PRECIPITATION, ANNUAL REGIME

Units, inches or millimeters. Totals include rain and the water content of snowfall.

Average Annual Total

Besides the amount at one or more representative stations, the estimated range over the area may be given. If an areal precipitation map is presented (fig. 4), the averages should be based on or adjusted to a standard period, discussed earlier. Annual averages at snow survey courses may be estimated from the April 1 snowpack water content (Farnes 1971). When lines (isohyets) are drawn for mountainous regions, using the topography as a guide, at best only a generalized picture is possible. Although average precipitation generally increases with elevation, heavier amounts can be expected in the usually windward slope and canyon locations and lesser amounts in the lee ("rain-shadow") locations.

Extreme Annual Totals

These are the amounts that have been observed in the wettest and driest calendar years or water years (October through September); note the period of record.

Monthly Average Precipitation

When plotted, the monthly average amounts at a station are usually shown by a bar graph (fig. 5). These amounts and seasonal totals are often stated as percentages of the annual total. The wettest and driest months or seasons, together with secondary peaks, may be noted.

Monthly Frequencies of Days with Precipitation

These frequencies give the average number or percent of days (or 24-hour periods) with various amounts, such as ≥ 0.01 inch (0.25 mm), ≥ 0.10 inch (2.5 mm), and ≥ 0.50 inch (12.7 mm).

Snowfall, Annual and Monthly Averages

Units, inches or centimeters. These amounts refer to the summation of depths of individual daily snowfalls, before melting or settling occurs. The percentage contribution of annual snowfall to total precipitation may be estimated, using an appropriate average ratio of snowfall to its water content. An overall ratio of 12 to 1 (12.0 inches [30cm] of newly fallen snow containing 1.0 inch [25 mm] of water) appears reasonable for many parts of the United States, though much variation can be expected among individual storms (Landsberg 1958).

Snow Cover; Snowpack

Information on snow cover, at daily observation stations, may include the average monthly and seasonal numbers of days with 1 inch or more of snow on the ground; also the maximum depths. Snowpack, at snow survey courses, refers to the average depth and water content on the scheduled monthly survey dates, or at least on a peak-season date such as April 1.

Runoff; Relation to Precipitation

In a climatic context, average annual stream discharge, or "runoff," is expressed in equivalent depth. This depth, in inches or millimeters, is derived from the runoff volume, reported in acre-feet or hectare-meters, divided by the size (acres or hectares) of the drainage area. The stream should have little diversion or reservoir storage; otherwise the published runoff data should adjust for this. The period of record used should, if possible, match that on which the normal precipitation is based.

The pattern of monthly average runoff, expressed in percentage of annual total, can be shown by the use of a bar graph,

[4]Finklin, Arnold I. Climate of the Howard Creek area, Lolo National Forest, Montana. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory; 1978, rev. 1981. Office report.

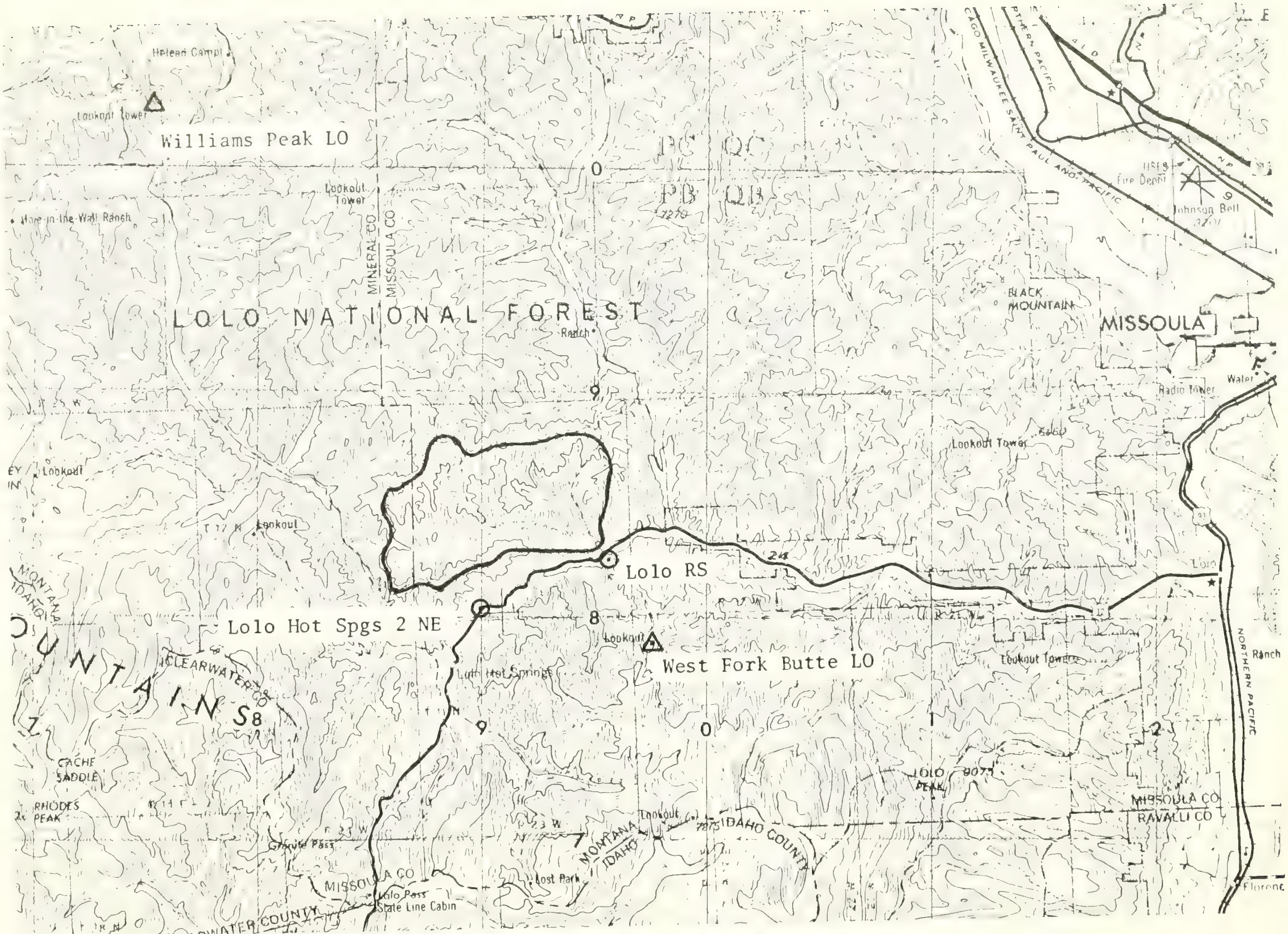


Figure 3.—Portion of map in U.S. Army Topographic Command Series, for sale by U.S. Geological Survey, showing topography of Howard Creek drainage (outlined), Montana, and locations of adjacent fire-weather or climatological stations. Elevation contours are at 200-ft intervals; sides of grid squares are 6 miles long.

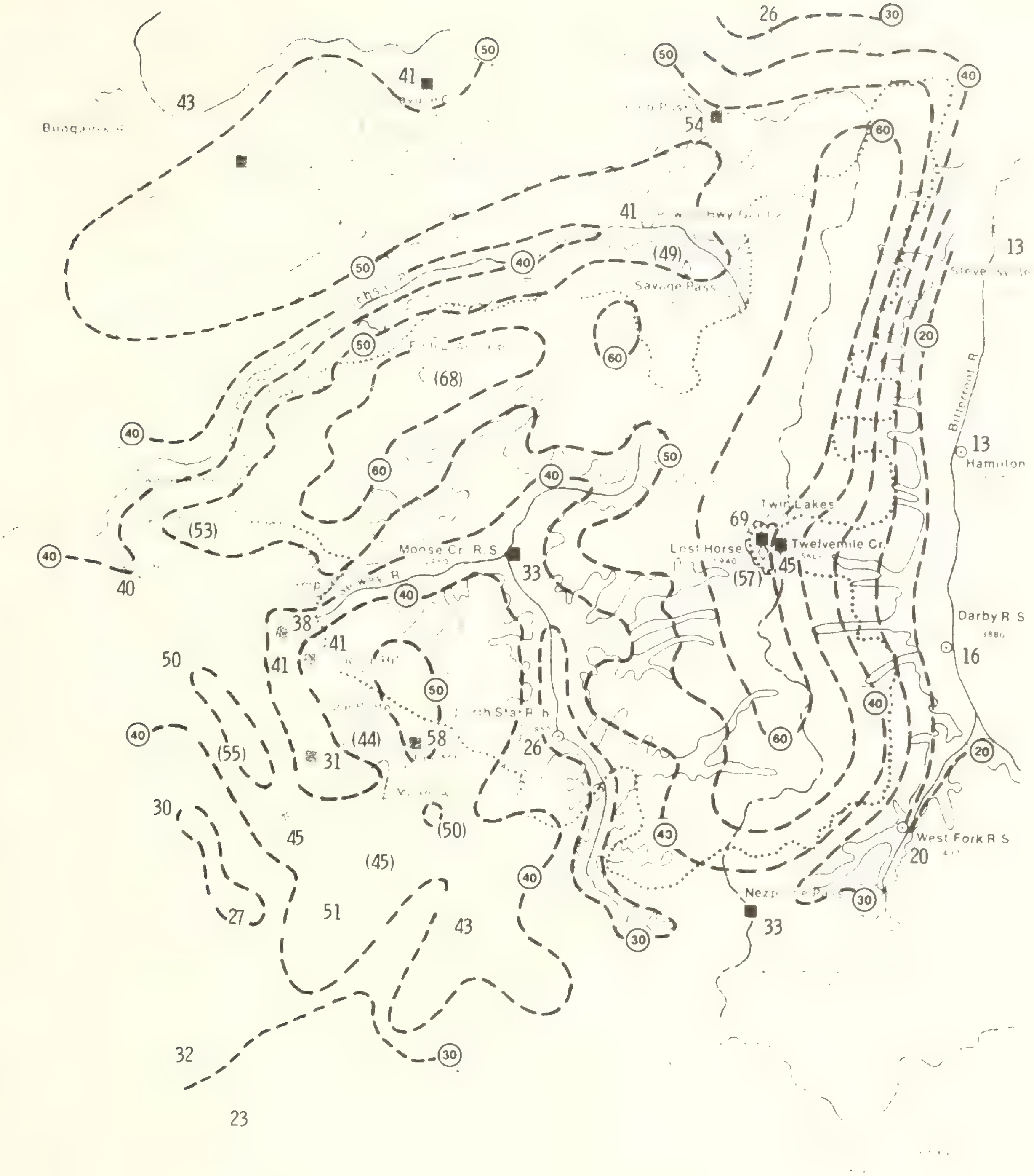


Figure 4.—Normal annual precipitation, inches, in or near Selway-Bitterroot Wilderness (outlined by dots), Idaho and Montana; based on or adjusted to 30-year period 1941–70. Amounts in parentheses are extrapolated from April 1 snowpack water content. Dashed lines (isohyets) are drawn and labeled at 10-inch intervals. Thin, irregular line is 5,000-ft elevation contour.

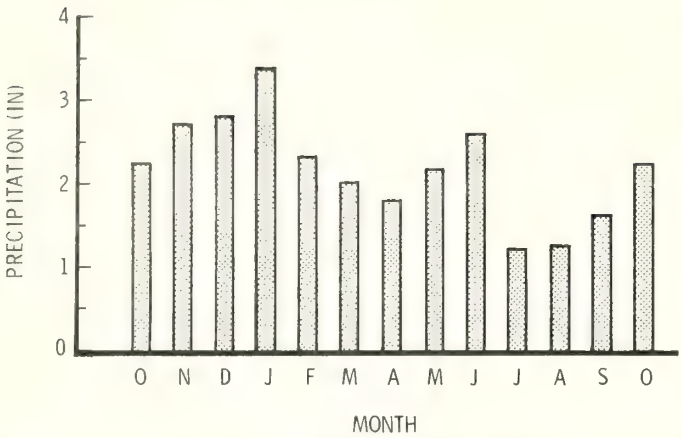


Figure 5.—Estimated normal (1941-70) monthly precipitation at climatological station near Howard Creek drainage, Montana, given in water-year sequence.

starting with October (first month of the water year); the cumulative water-year runoff, adding the monthly percentages, by a superimposed curve. The corresponding monthly and cumulative precipitation, as averaged from several stations in or near the drainage area, may be portrayed in the same diagram (fig. 6).

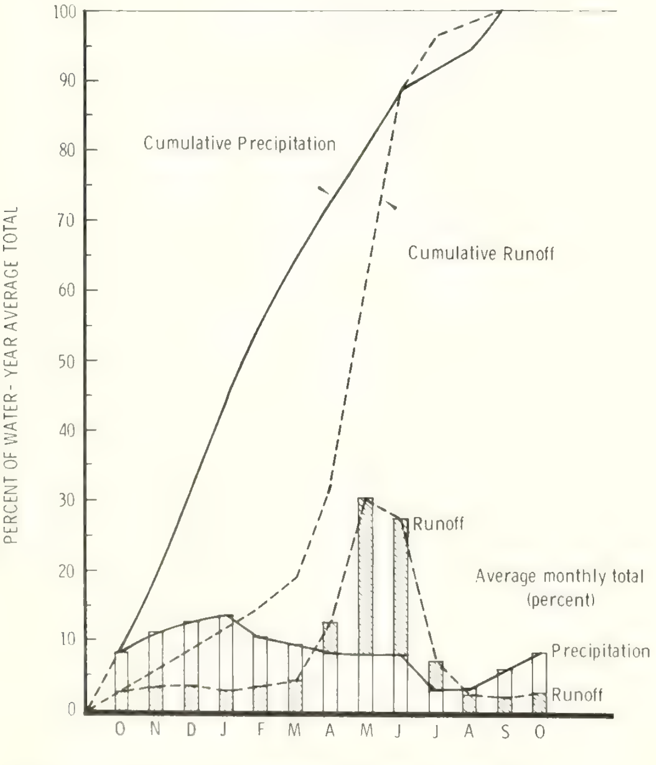


Figure 6.—Comparison of seasonal regimes of precipitation in Selway-Bitterroot Wilderness vicinity (average based on 5 stations) and Selway River runoff near Lowell, Idaho; based on or adjusted to 30 years 1941-70. Values are adjusted to 30-day months.

PRECIPITATION DURING FIRE SEASON

Average Rainfall:[5] 10-day and Monthly

A data summary obtainable by computer program is illustrated in table 6 (appendix). Use of a bar graph to depict 10-day average values is shown in figure 7 (lower panel). Though such details should ideally be based on or adjusted to the standard 30-year normal period, 20 years of data may suffice with smoothing (the need is evident from fig. 1). Methods of adjustment and smoothing are described in the final section of this report.

Monthly or Seasonal Extremes

These amounts, greatest and least observed, can be obtained in part from the above tabular output.

Frequency Distribution: Daily, 10-day, and Monthly Amounts

The frequencies are expressed as percentages of all observations in the corresponding time frame. Examples are found in tables 7 and 8 (appendix). These show a positive skewness typical of rainfall, particularly for the shorter time periods. That is, there is a wider range of amounts above the average than below. Correspondingly, the frequency of amounts below the average is greater.

The frequencies can be plotted in 10-day sequence, as in figure 7 (upper panel). In this example, the frequencies—given for the full season—were in part estimated through relationships with the corresponding 10-day average rainfall. An example of such relationship is seen in figure 8. For future reference we will term this type of graph, which can be used for other climatic elements, an "F-A" (frequency-versus-average) graph. Plotting of this graph is described in the final section.

In using this type of graph for frequency estimates, the horizontal scale is entered at the 10-day average amount for any portion of the fire-weather season. As an example, we may seek the frequency (or probability) of 24-hour rainfall ≥ 0.10 inch during September 11-20. Given the previously obtained normal average of 0.66 inch (fig. 7), projection of lines to and from the appropriate curve in figure 8 gives a frequency of 18 percent.

THUNDERSTORMS

Average Number of Days

The counted days or 24-hour periods include one or more separate storm occurrences. Tabulations may be for individual locations (from which the storms are observed) or for a broader area (storms observed from any one of several stations). For monthly resolution, averages should be based on at least 10 years of complete data; for 10-day periods, at least 15 or 20 years with some smoothing applied. Averages can be given in numbers of days (nearest whole number) or as percentages of all days.

It may be difficult, however, to obtain adequate thunderstorm data. On the Fort Collins fire-weather data library tapes,

[5]Here we will use the term rainfall, the form in which most of the precipitation occurs during the fire-weather season.

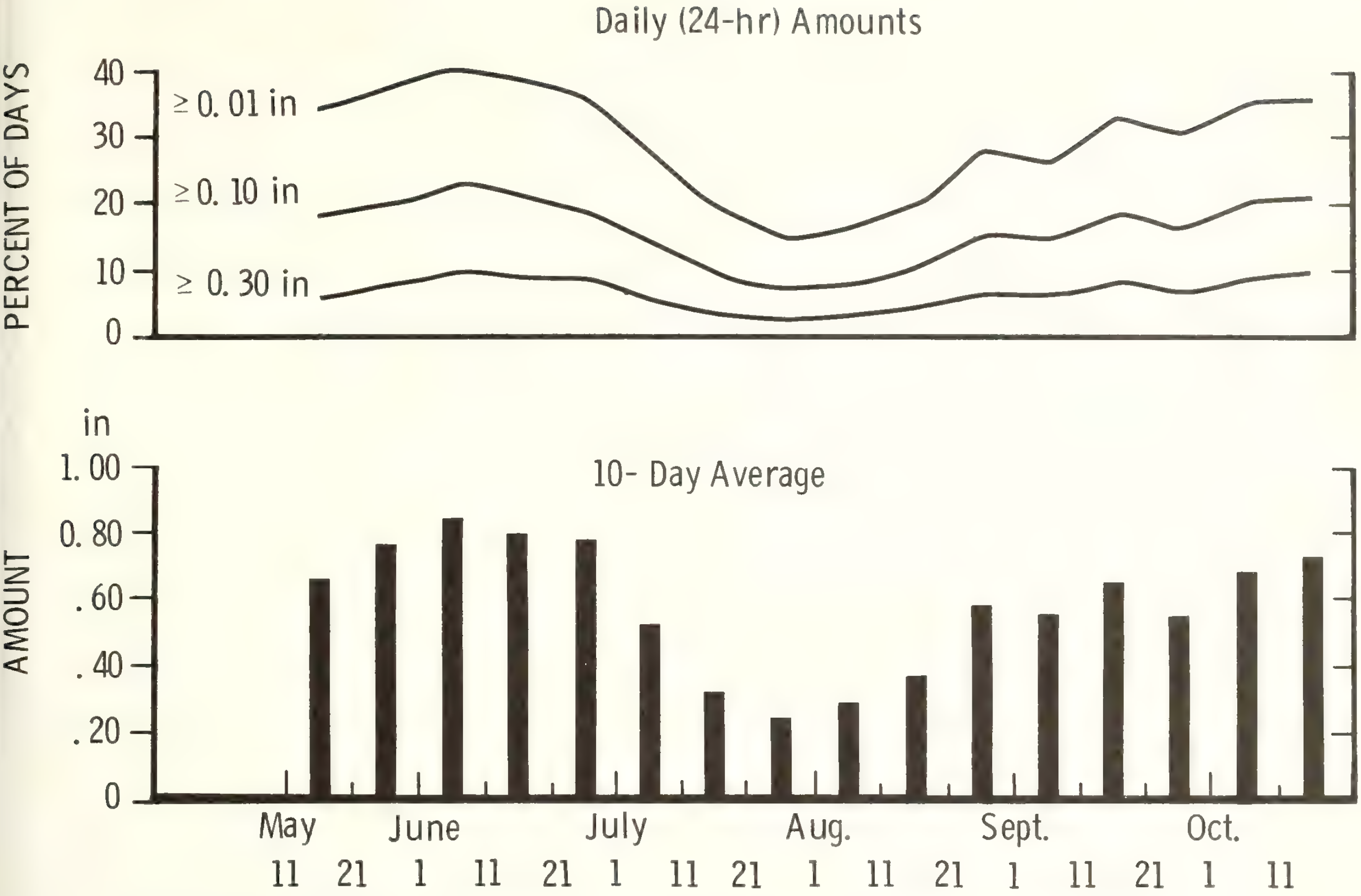


Figure 7.—Fire-season regime of precipitation estimated for lower canyon area, Howard Creek drainage, Montana. Lower panel: average 10- (or 11-) day accumulation, plotted at middle of periods. Upper panel: corresponding percentage frequency of specified daily amounts.

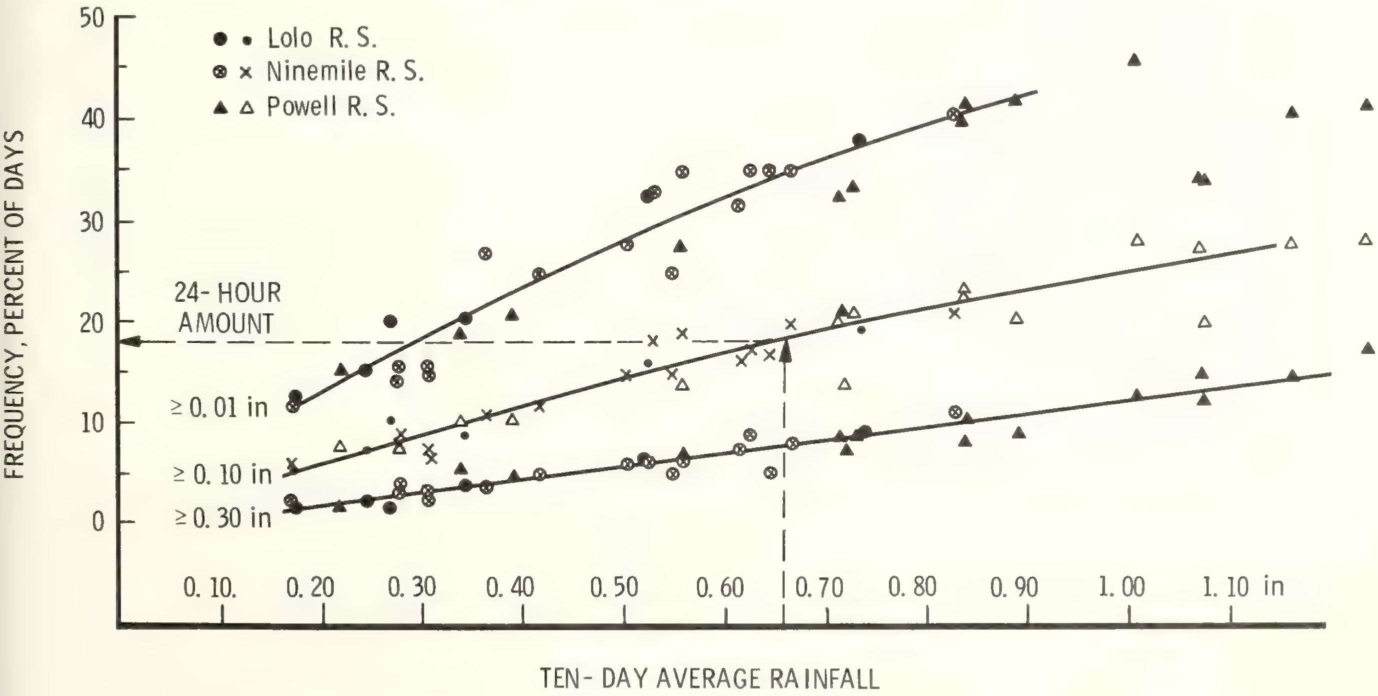


Figure 8.—"Frequency-versus-average" diagram, showing relationship between 10- or 11-day average total rainfall and percentage of days (24-hour periods) with the specified amounts; area surrounding Howard Creek drainage. Based on the indicated stations, May 11-October 20, 1954-70, except July 1-August 31, 1954-67, at Lolo Ranger Station. Projected lines and arrows show how to estimate frequency of ≥0.10 inch, given average rainfall of 0.66 inch.

the present AFFIRMS format provides for storm occurrence only by use of a Lightning Activity Level, part of the new National Fire Danger Rating System (Deeming and others 1972; Deeming and others 1977). This level is available for relatively few years to date. If the needed data can be gathered from original fire-weather forms or earlier tape printouts, the lookout observations should take precedence over those from ranger stations because of generally greater visibility and 24-hour duty.

The frequency of thunderstorm days may, alternatively, be estimated from tabulations (in "Local Climatological Data" summaries) for the Weather Service airport stations. Broad-scale monthly and annual patterns are shown on maps by the U.S. Weather Bureau (1952); an updated annual map is presented by Baldwin (1973). The criteria for thunderstorm occurrence differ somewhat. Present instructions for fire-weather stations include either visible lightning, as far as 30 miles away, or audible thunder. Thunderstorm days counted at the airport stations consider only audible thunder. Due to the traveling nature of storms, however, the two sets of data tend to become compatible. The tendency for more thunderstorm activity over mountain areas may present a greater source of difference.

TEMPERATURE, ANNUAL REGIME

Units, degrees Fahrenheit (F) or Celsius (C). Temperature, in our context, refers to measurements about 5 feet (1.5 m) above the ground surface.

Annual Mean

This is based on the 12 individual monthly averages or "means," which are taken as midpoint values between the average daily maximum and minimum temperatures. These values, which are close to actual 24-hour averages, smooth out some of the local daytime and nighttime effects.

Monthly Averages

The course of monthly average temperatures (both maximum and minimum) can be shown by curves (fig. 9). If 30-year normals are not available, averages based on 15 to 20 recent years will give a good approximation. The range between the warmest and coldest months may be noted; also the average daily ranges between maximum and minimum temperatures.

Interpretation factors.—Topographic setting, as well as elevation, can strongly affect the average temperature values. Year-round data are sparse for mountaintop and slope locations in the United States; some of the existing data have been specially obtained in government or university research studies. In making extrapolations for such locations, general relationships (described, for example, by Schroeder and Buck 1970) can help.

In general, afternoon (or daily maximum) temperatures decrease with elevation gain, though the average "lapse rate" varies with the region and time of year. Over the western United States, the lapse rates (between adjacent stations) average mostly between 3.5° and 5.0° F per 1,000 ft (6.4° and 9.0° C per 1 000 m) during spring and summer, but generally less in late autumn and early winter—when they are no more than 2.5° F per 1,000 ft (4.5° C per 1 000 m) in many areas. (These rates are based on data tabulations by the author.) An exception occurs near the Pacific coast, particularly in the California coastal ranges, where "marine-air" inversions are common during the summer. Nighttime (or daily minimum) temperatures may increase with elevation, due to inversions

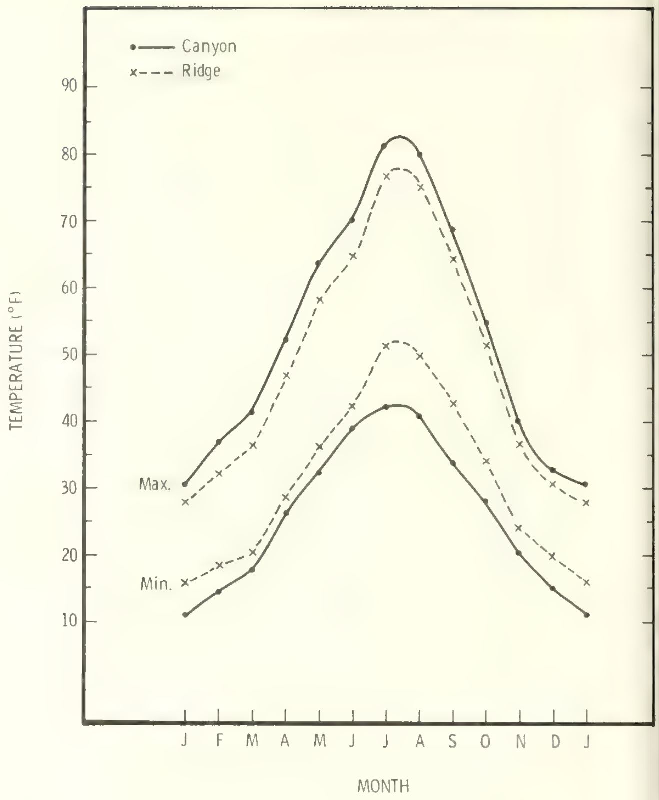


Figure 9.—Estimated normal (1941-70) monthly average daily maximum and minimum temperatures, for 24-hour period ending at midnight; Howard Creek drainage, Montana. At lower canyon location (4,000-ft elevation) and ridge location (5,400 ft).

from radiational cooling and downslope air drainage (Schroeder and Buck 1970). Further details are given in the section covering the fire season. Baker (1944) presents graphs of average temperature versus elevation in various mountain areas of the West. He does advise caution, however, because of the limited availability and representativeness of stations, particularly at higher elevations.

One should be aware of the effect of differing daily observation times on average maximum and minimum temperatures. As is discussed in the final section, there can be a resulting difference of 2° F (1° C) in the average daily maximum.

Extreme Values

These are the highest and lowest temperatures observed during a stated period of years. The extremes may be given for particular months or seasons.

Freezing Temperature Threshold Dates

These are the average last dates in spring and first dates in autumn with minimum temperatures ≤32° F (0° C) and ≤28° F (-2° C). The number of days between dates is commonly designated as the length of the frost-free season or growing season, but these are oversimplified terms.

For such tabulations, as in NOAA (1971) and annual "Climatological Data," State summaries, the National Climatic Center uses June 30-July 1 as the season division. For western mountain areas, such as the Northern Rockies, July 31-August 1 appears more suitable. This is normally the warmest time of

year; frosts or freezing temperatures may occur in June and early July but perhaps not again until late August or in September. If required, threshold dates for lower minimum temperatures, down to 16° F (-9° C), are also published.

RELATIVE HUMIDITY, ANNUAL REGIME

Units, percent. By definition (Schroeder and Buck 1970), relative humidity is the percentage ratio of the air's actual water vapor pressure to the saturation (or maximum possible) vapor pressure at the existing temperature. This maximum pressure increases with increasing temperature. Thus, if there is little change in actual vapor pressure, the relative humidity varies inversely with the temperature. This relationship largely accounts for the occurrence of minimum relative humidity values in the afternoon and maximum values near dawn. The vapor pressure is directly related to the dewpoint—the temperature to which air must be cooled to reach saturation and condensation.

Monthly Averages

Outside the season of fire-weather observations, available relative humidity data are limited to the network of airport (or airways) weather stations. (This excludes older data from former stations mostly in downtown city locations.) Before 1982, averages were given in monthly "Climatological Data," State summaries, for the times corresponding to 0000, 0600, 1200, and 1800Z (Greenwich meridian time). These hours range from 1 and 7 a.m. and p.m. eastern standard time to 4 and 10 a.m. and p.m. Pacific standard time. Averages are also given for the intermediate 3-hourly times in "Local Climatological Data."

As with temperature, monthly averages based on 15 to 20 years will give a good approximation of the normal. Twenty-four hour averages can be approximated from those of the above times. The averages at the airport stations may serve only as an indicator of the monthly trends in the forest and mountain areas; they should be more representative of grassland areas. Averages (24-hour) can also be interpolated, within perhaps 5 or 10 percent accuracy, from lines drawn on maps in ESSA (1968); the lines have been adjusted somewhat over the mountain areas.

TEMPERATURE AND RELATIVE HUMIDITY DURING FIRE SEASON

These two elements are discussed together—because of their relationship (described above) and because the data are summarized in the same types of tables and graphs. The temperature in this context is often termed the "dry bulb."

Afternoon Averages, 10-day and Monthly

Examples of computer program output are shown in table 9 (appendix); graph presentation of averages in figure 10. A map may be included for a peak season month (fig. 11). As indicated by figure 2, 10-day details should, if possible, be based on at least 20 years of data at an unchanged observation time; however, 15 years, together with smoothing (final section), may suffice.

For estimating averages at another location, where elevation difference is more than a few hundred feet (100 m), appropriate lapse rates may be applied. Using data from adjacent lookouts, the afternoon temperature lapse rate between ridgetop or mountaintop locations should be close to 3.5° or 4.0° F per 1,000 ft (6.4° to 7.3° C per 1 000 m) over much of the mountain West. The corresponding average relative humidity usually increases with elevation, with a change of about 3 percent per 1,000 ft (305 m) in the Northern Rocky Mountains. An adjustment of 4 percent per 1,000 ft is indicated in the Pacific Northwest region by Graham and Lynott (1971). Afternoon temperature lapse rates from canyon or valley locations to adjacent ridgetops should, outside the Pacific coastal influence, generally average somewhere between 3.5° and 5.0° F per 1,000 ft (6.4° and 9.0° C per 1 000 m). However, temperatures at slope locations can easily differ by 3° F (2° C) or more from laspe rate estimates, depending on aspect as well as vegetative cover.

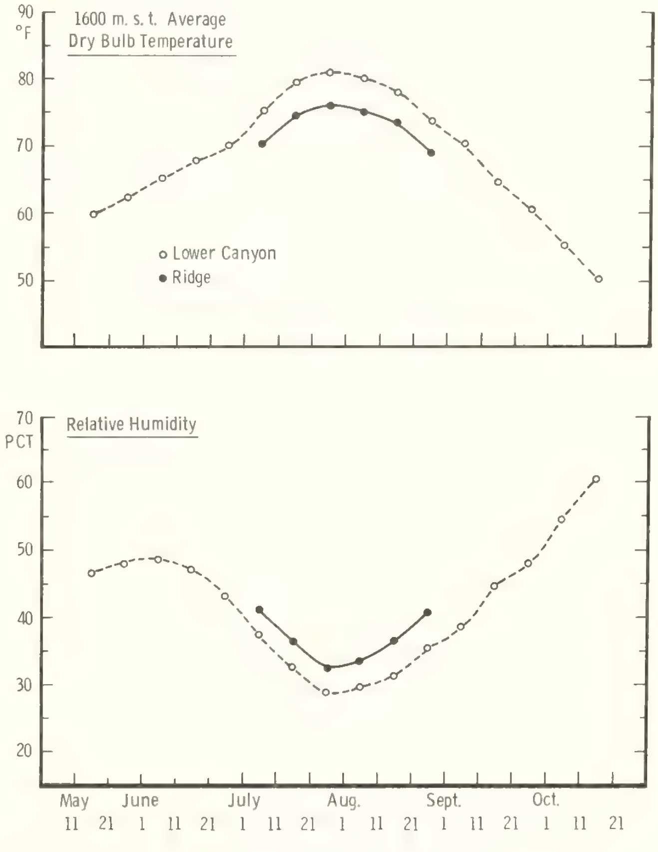


Figure 10.—Fire-season regimes of 10- or 11-day average dry bulb and relative humidity at 1600 m.s.t., Howard Creek drainage. Curves are fitted to smoothed 1954–70 averages (plotted at middle of periods) estimated for lower canyon (4,000 ft) and ridge (5,400 ft) locations.

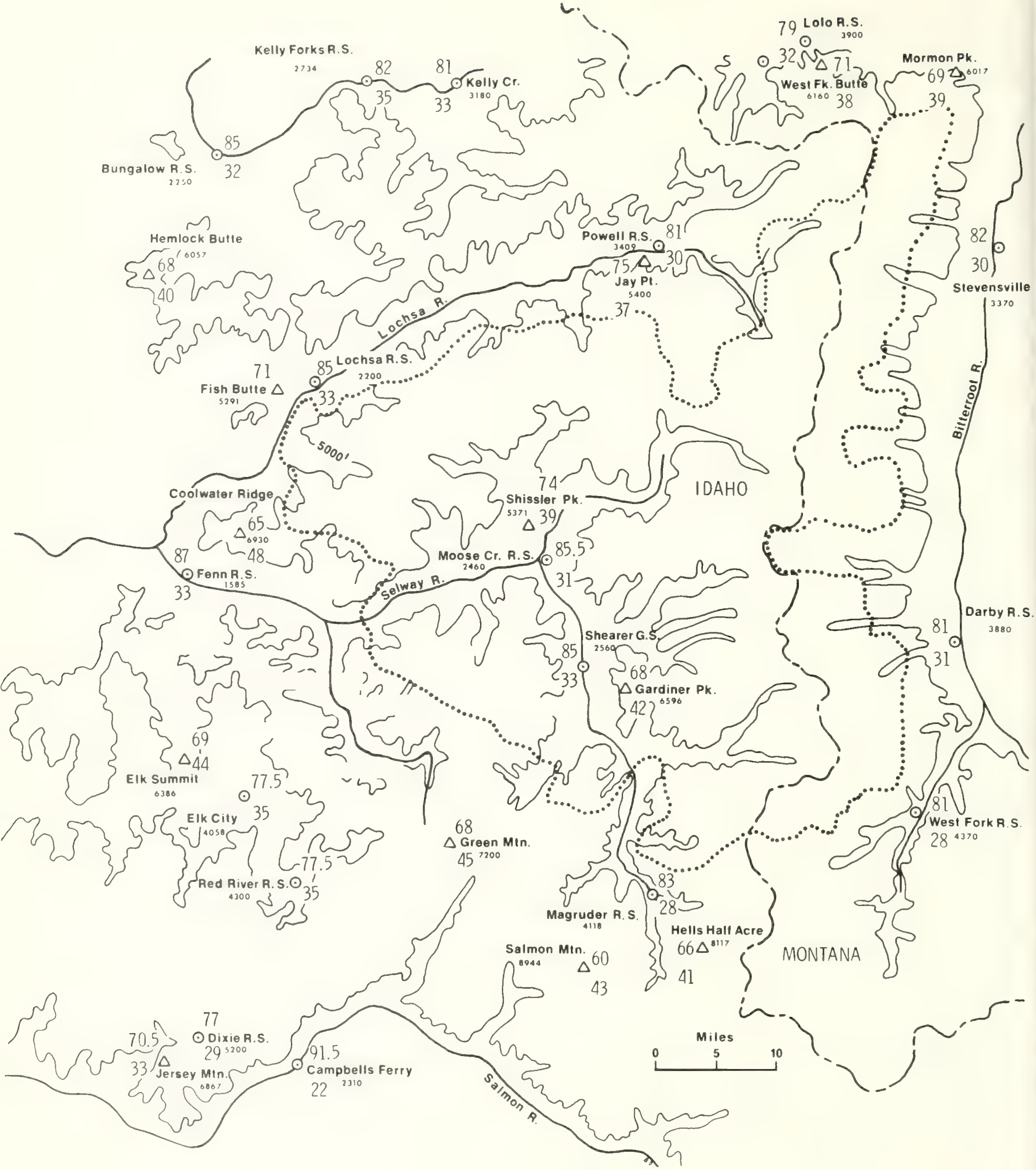


Figure 11.—Average dry bulb temperature, °F (top number), and relative humidity, percent (bottom), at 1500 P.s.t., July, in or near Selway-Bitterroot Wilderness.

Afternoon Frequency Distributions

Examples are shown in table 10 (appendix) and in figure 12. The frequencies for such a figure are obtained by summing the percentages given in each of the table classes lying above the specified dry bulb thresholds and below the specified relative humidity thresholds. These threshold values are generally at intervals of 10° F (5° C) and 10 percent, respectively. The plotted frequencies may be smoothed (as described in the final section) or, as in figure 12, the fitted curves smoothed. Using these curves, various percentile values can be interpolated for any portion of the season. Thus, in figure 12, the 10th percentile value of relative humidity during July 1-10 is about 16 percent.

For locations with no data or with only a short record, the frequencies can be estimated from adjacent stations by use of "F-A" relationships previously described for precipitation. Examples for dry bulb are given in figure 13; for relative humidity in figure 14. Thus, using figure 13 (left panel), if the 10-day average dry bulb is 80° F (27° C) at a canyon location, the estimated frequency of days with ≥ 90° F (32° C) is 12 percent. Separate graphs are required, at least for dry bulb, for the groupings of ranger stations and lookouts. The sets of curves would differ further for higher-elevation lookouts.

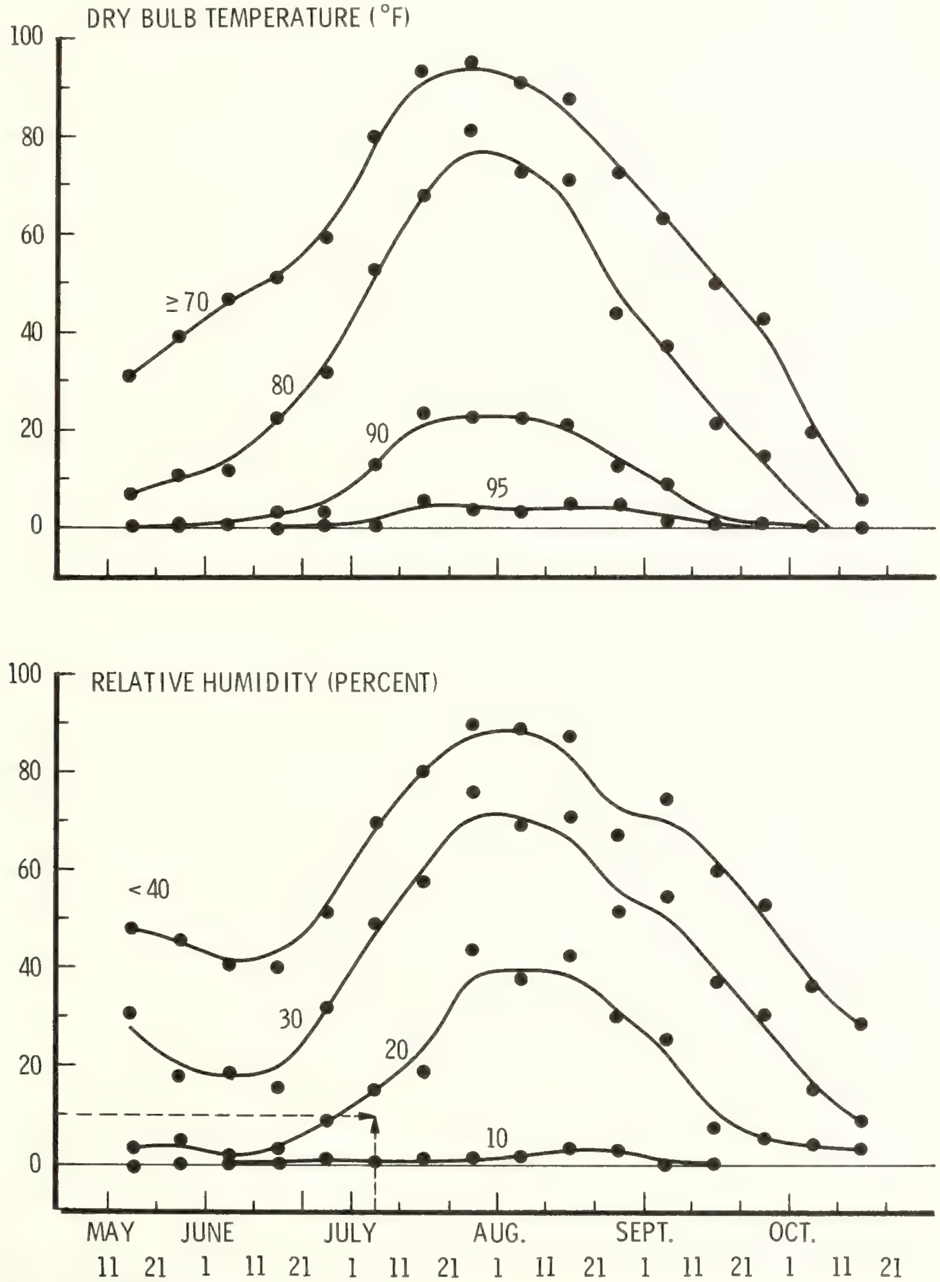


Figure 12.—Fire-season frequencies of specified dry bulb (upper panel) and relative humidity (lower panel) at 1600 m.s.t., Ninemile Ranger Station, Mont.; based on data during 1954-70. Curves, smoothed by 1-4-1 weighting, are fitted to frequencies (plotted at middle of 10- or 11-day periods). Projected lines and arrows show how to estimate 10th percentile value of relative humidity for July 1-10.

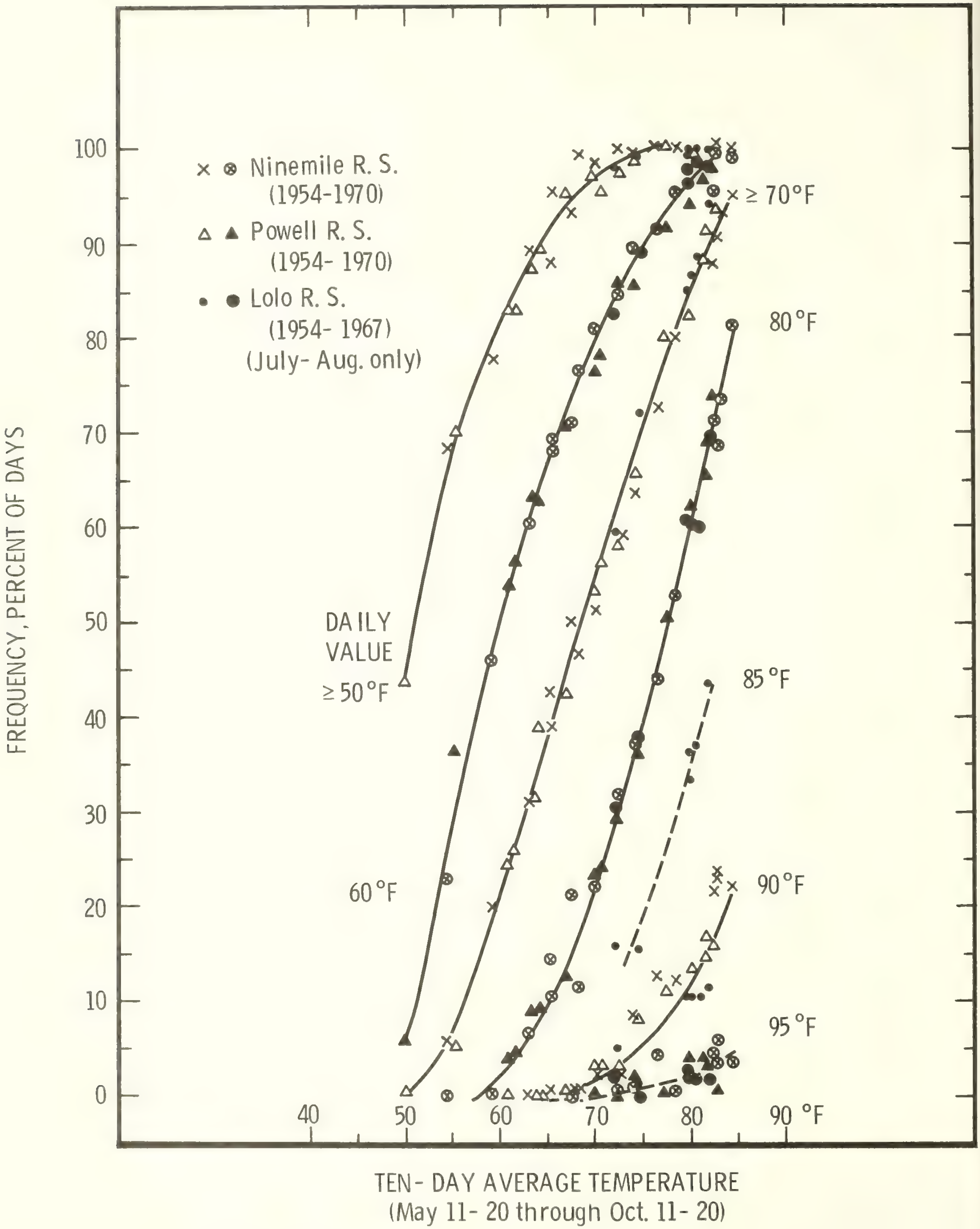
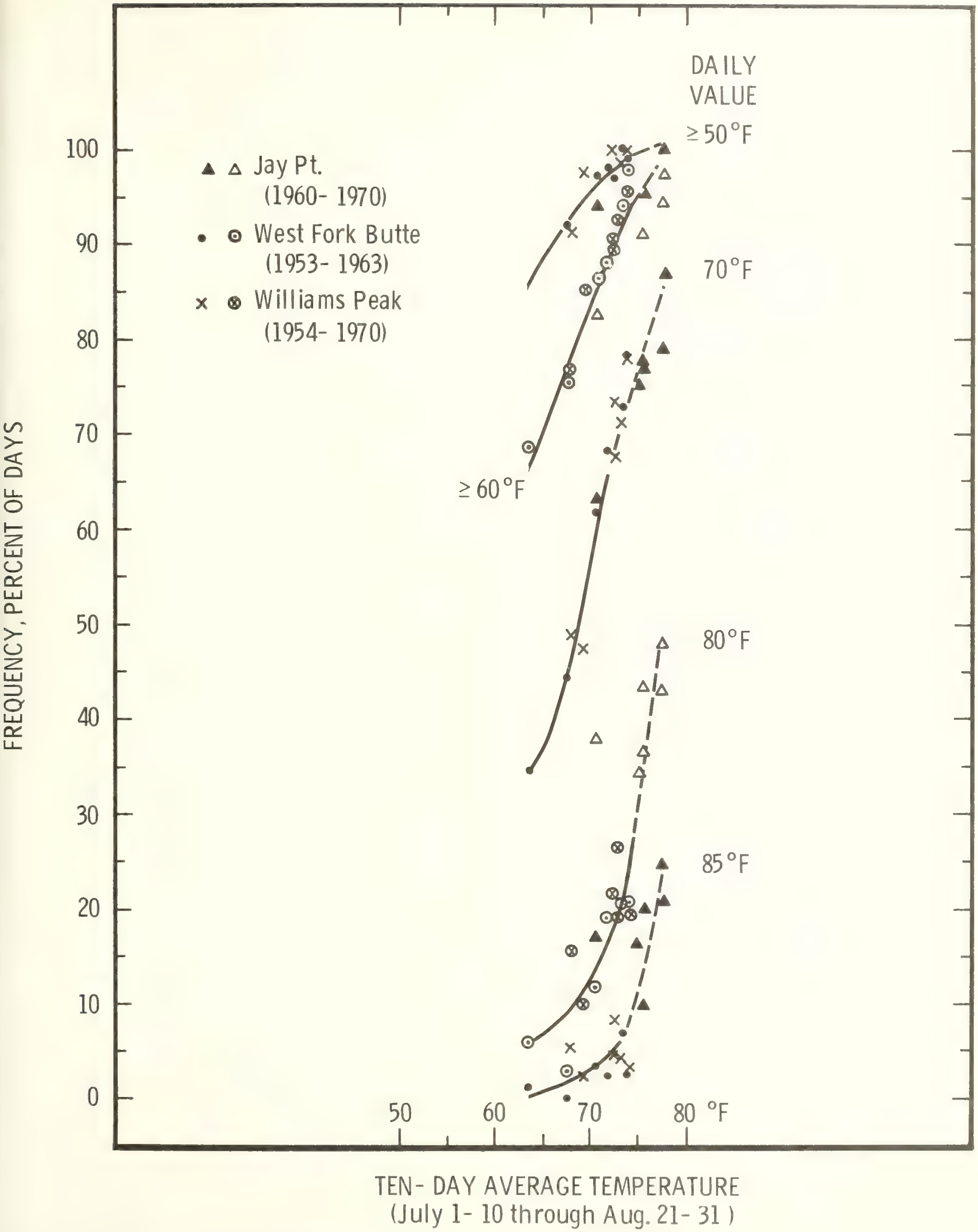


Figure 13.—"Frequency-versus-average" relationships (see fig. 8) for dry bulb at 1600 m.s.t.; area surrounding Howard Creek drainage. Based on indicated ranger stations (left panel) and lookouts (right panel).


DAILY VALUE
≥50°F
70°F
≥60°F
80°F
85°F
Jay Pt. (1960-1970)
West Fork Butte (1953-1963)
Williams Peak (1954-1970)
FREQUENCY, PERCENT OF DAYS
100
90
80
70
60
50
40
30
20
10
0
50
60
70
80 °F
TEN-DAY AVERAGE TEMPERATURE
(July 1-10 through Aug. 21-31)

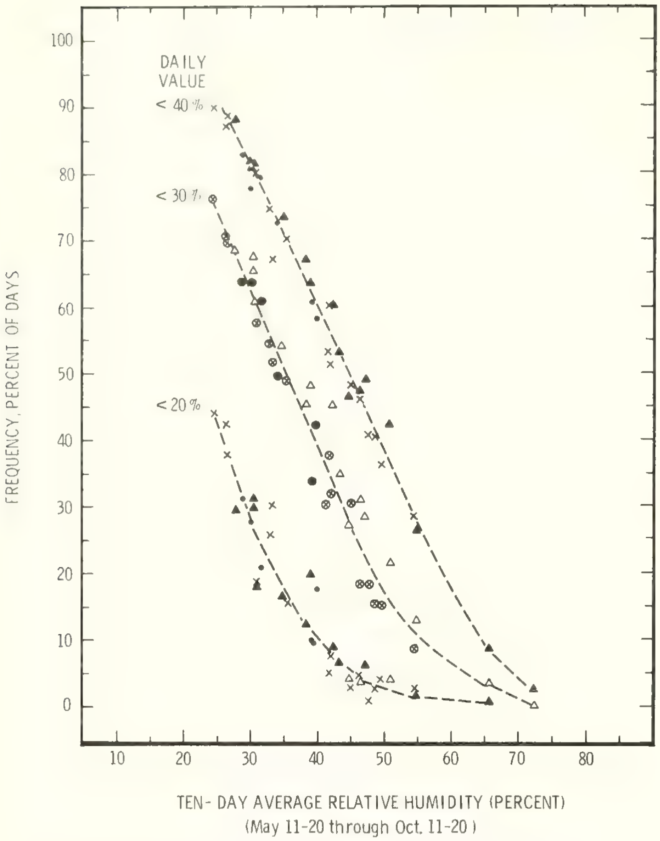


Figure 14.—"Frequency-versus-average" relationships for relative humidity at 1600 m.s.t., based on ranger stations as in figure 13.

Daily Maximum and Minimum Temperatures

Examples of summarized data are shown in tables 11 and 12 (appendix). The seasonal trend of average daily maximum temperature closely parallels that of the afternoon dry-bulb (as graphed in fig. 10). Likewise, average lapse rates of maximum temperature are similar to those already noted for the dry bulb. Included in this similarity is an overall lapse rate of about 4.0° F per 1,000 ft (7.3° C per 1 000 m) for spring and summer maximum temperatures in the mountain area of western North Carolina (from data listed by Cox 1923).

The lapse rate of 24-hour average temperature is brought closer to (or below) the sometimes quoted climatic lapse rate of 3.3° F per 1,000 ft (6.0° C per 1 000 m) (Baker 1944; Baldwin 1973) by the generally smaller lapse rates of nighttime (and daily minimum) temperatures. These smaller rates are related to the inversions that typically occur in fair weather. In the northern Rocky Mountain area, average minimum temperatures during July and August are higher at lookouts than in canyons or valleys 3,000 to 5,000 ft (900 to 1 500 m) lower in elevation. The average lapse rates, thus, do not necessarily represent a continuous gradient along a slope.

Where the slope has an open exposure, average nighttime temperatures may increase 10° F (6° C) or more within a rise of 1,000 ft (300 m) above a valley, peaking in the "thermal belt." (Examples are given by Cox 1923; Hayes 1941; Reimann 1959; MacHattie 1970.) This belt, where the highest 24-hour average temperature occurs, is centered at or near the typical inversion top, above which the nighttime temperature decreases. The decrease appears to average near 2.0° to 2.5° F per 1,000 ft (4° C per 1 000 m) in the Northern Rockies and western North Carolina. In narrow canyon areas, particularly where slopes are well forested, inversions in summer may average only 2° to 4° F in the lower 1,000 ft (1° to 2° C in 300 m); examples observed in the Selway-Bitterroot Wilderness area in Idaho are given by Finklin (1983).

Nighttime (Maximum) Relative Humidity

Because of the data uncertainties, only monthly averages are suggested. Observations of the daily maximum (and minimum) relative humidity, from hygrothermograph traces, are recorded at many fire-weather stations, but caution is advised (footnote 2). Alternatively, the average maximum relative humidity may be approximated from the generally inverse relationship with temperature. A simple procedure is to estimate the average maximum humidity as the value found in a psychrometric table (available in Fischer and Hardy 1976), given as inputs the average daily minimum temperature and the corresponding monthly average afternoon dewpoint. This may be done for valley and canyon locations but, as discussed below, some adjustment of dewpoint is recommended at least for higher terrain. The dewpoint may itself have to be obtained indirectly from the psychrometric table, as it is not available from the tapes at the National Fire-Weather Data Library.

To illustrate the simple procedure, we will use respective minimum temperature and afternoon dewpoint averages of 50° F and 44° F at a station elevation of 3,000 ft (915 m); the appropriate psychrometric table then shows a relative humidity of 81 percent. Accuracy of such an estimate much depends on how close the afternoon dewpoint is to that actually occurring around dawn. In the above example, a 2° F (1° C) difference in dewpoint would yield a 6 or 7 percent difference in the relative humidity estimate.

At valley locations with strong nighttime cooling, particularly in forest areas, the minimum temperature may average slightly lower than the afternoon dewpoint. An example is seen in comparing table 11 with table 9 (appendix). Such a condition indicates that dew or frost formation has removed moisture from the air. The relative humidity (at instrument shelter level) may then average about 95 percent around dawn.

For ridgetop or mountaintop locations, estimates of summer nighttime relative humidity should generally use a dewpoint lower than the observed afternoon value; lookout data suggest a difference of at least 3° F (2° C) in the western States. This difference follows from the typical diurnal variation during fair weather, related to upslope breezes during the day and downslope breezes at night (Schroeder and Buck 1970). The daytime air movement from lower elevations brings relatively high afternoon dewpoints on the mountains. At night, the dewpoints tend to decrease to those of the surrounding atmosphere. This change contributes to typically smaller relative humidity recovery than in the valleys and canyons, but the smaller nighttime temperature drop on the mountains is a greater factor. By dawn, the humidity may average 30 percent or more lower than in canyon and valley bottoms.

WIND, ANNUAL REGIME

Units of speed, miles per hour (mi/h) or kilometers per hour (km/h). Directions are those from which the wind is blowing.

The standard surface measurements are at a height of 20 ft (6 m) above the ground in an open area.

As with relative humidity, year-round wind data are limited mostly to the network of airport (or airway) stations. Caution is advised in applying these data to forest and mountain areas. Windspeeds and directions can be greatly modified by surrounding timber and the local topography. Monthly average speeds given in ESSA (1968) and "Climatological Data," State summaries, are based on the entire day; averages at 3-hour intervals are given in "Local Climatological Data." The latter two publications also list the resultant speeds (obtained by vectorial averaging), which for our purposes should not be used. Prevailing (most frequent) directions, rather than resultant directions, are given only in ESSA (1968).

WIND DURING FIRE SEASON

Afternoon Direction and Speed

Monthly data resolution should be adequate. The standard windspeed at fire-weather stations is a 10-minute average taken at the afternoon observation time. While in many areas this time may closely represent the hour of highest average speed, winds can be stronger at other times on individual days. Within the 10-minute observation period, higher speeds can be expected over shorter durations. Crosby and Chandler (1966) found, at Salem, Mo., the probable maximum 1-minute average speed was generally 4 or 5 mi/h (up to 8 km/h) higher than the 10-minute average.

A basic summary of wind data is illustrated by table 13 (appendix). This gives combined frequencies of speeds and directions, together with average speeds. Directions are tabulated to eight points of the compass. Such a summary should be based on at least 10 years of data.

Prevailing wind directions in mountain valleys or canyons are generally up-valley (toward higher elevations) during the afternoon; opposing broader-scale, or "general," winds may dominate in less sheltered valleys. Exceptions have been noted to result from sea-breeze influences in parts of California (Schroeder and Buck 1970); also from spillover, through a low pass, of an up-canyon breeze from the other side of a mountain ridge. The afternoon winds are normally stronger at the lookout locations than at nearby ranger stations but overall elevational gradients cannot be given (fig. 15). The differences between canyon and mountaintop may vary more with local topographic effects or exposure than with elevation. Speeds at adjacent airports, usually in more open locations, tend to average higher than those observed at ranger stations.

Afternoon Frequency of Stronger Winds

The percentage frequencies of days with various threshold windspeeds can be obtained (by appropriate summation) from the computer output illustrated in table 14 (appendix); also from table 13 (appendix). As an example, using table 14, the frequency of July days with an observation of ≥ 15 mi/h (24 km/h) at West Fork Butte is found by adding the values in the "total" rows below the boxes for speeds of 15 to 19 mi/h and ≥ 20 mi/h. These totals (given in percent and tenths, decimal point omitted) are 4, 78, 51, 23, 8, 4, 8, 12, 8, 8, 4, and 4—adding up to 212, or 21 percent of all days.

An "F-A" graph may be plotted, relating average (monthly or seasonal) windspeed at a station and frequency of observed higher windspeeds (fig. 16). This requires data from several stations in an area, representing a sufficient range in average speed. Frequencies can then be estimated at other locations for which only the average speed is available.

Nighttime Wind

Except for early morning fire-weather observations prior to 1950 (and data from research studies), nighttime wind conditions in specific forest areas are left to inferences and generalities. In general, during the fire season, nighttime winds in mountain topography are downslope and down-valley (or down-canyon). They will usually be very light in bottom locations where temperature inversions are strong (as indicated by large daily temperature ranges). Higher speeds may be expected, however, where the down-canyon direction is alined with that of the "free-air" wind.

On the higher mountaintops, prevailing winds should generally continue from near the afternoon directions. Windspeeds on such terrain have been characterized as tending to increase at night (Baughman 1981). Available observations give mixed findings, with nighttime decreases on some mountains in the southwestern United States (Court 1978). Average nighttime increases did occur at two of three lookouts that had continuous recording charts in southern Idaho (Hanna 1933). The average diurnal curves, covering 4 or 5 summers, showed distinct differences, reflecting the importance of local topographic factors. Mountaintop winds may decrease by morning. At lookout stations in the Northern Rockies, speeds at the former 8 a.m. observation time averaged anywhere from 1 to 6 mi/h (up to 10 km/h) lower than in midafternoon. Hourly data from RAWS locations will provide more specific knowledge and will increase the base from which estimates may be made for other locations.

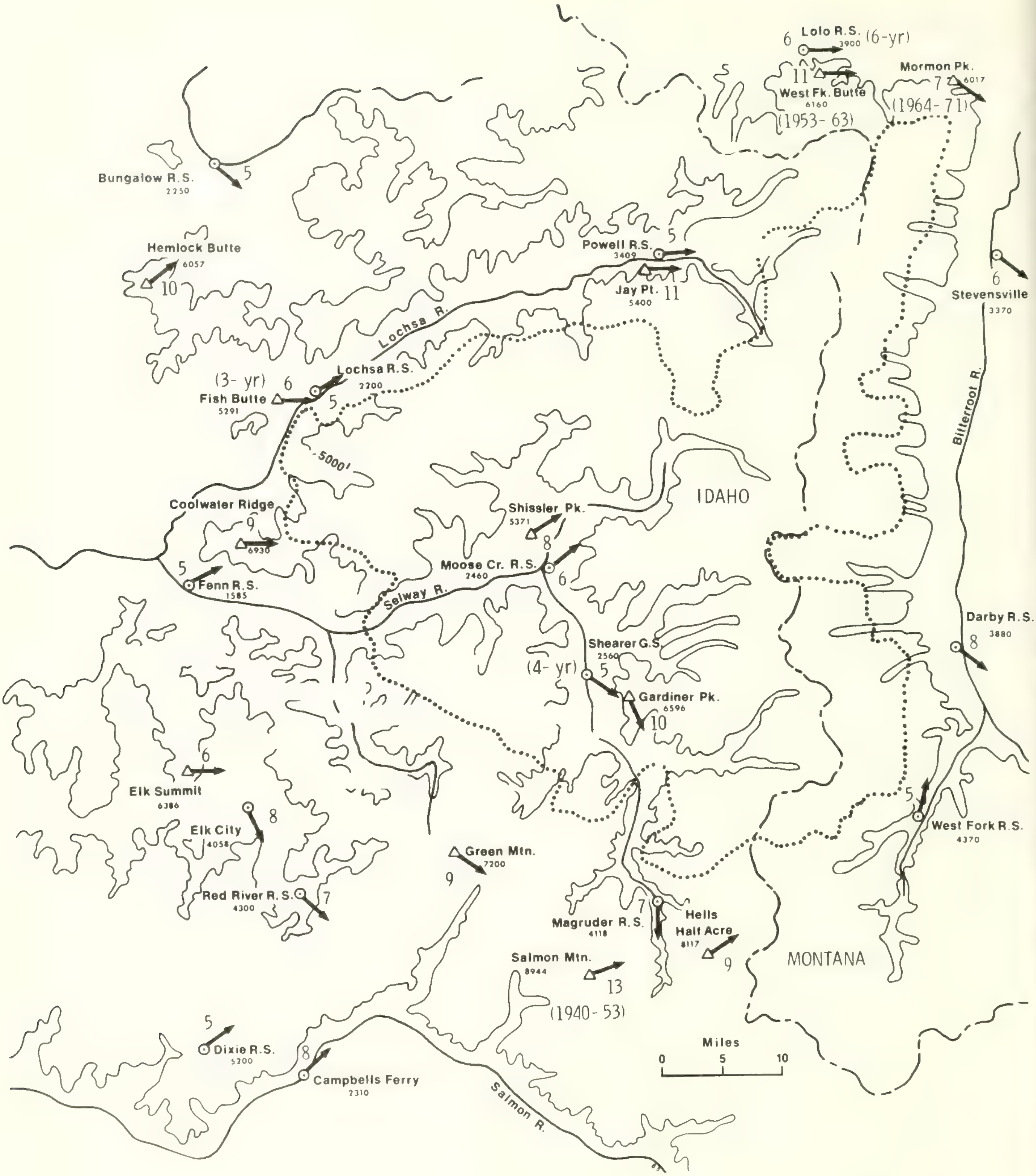


Figure 15.—Average windspeed, in miles per hour, and prevailing (most frequent) direction at 1500 P.s.t., July and August combined; in or near Selway-Bitterroot Wilderness. Based on 1961–70, except as noted. Arrows point downwind.

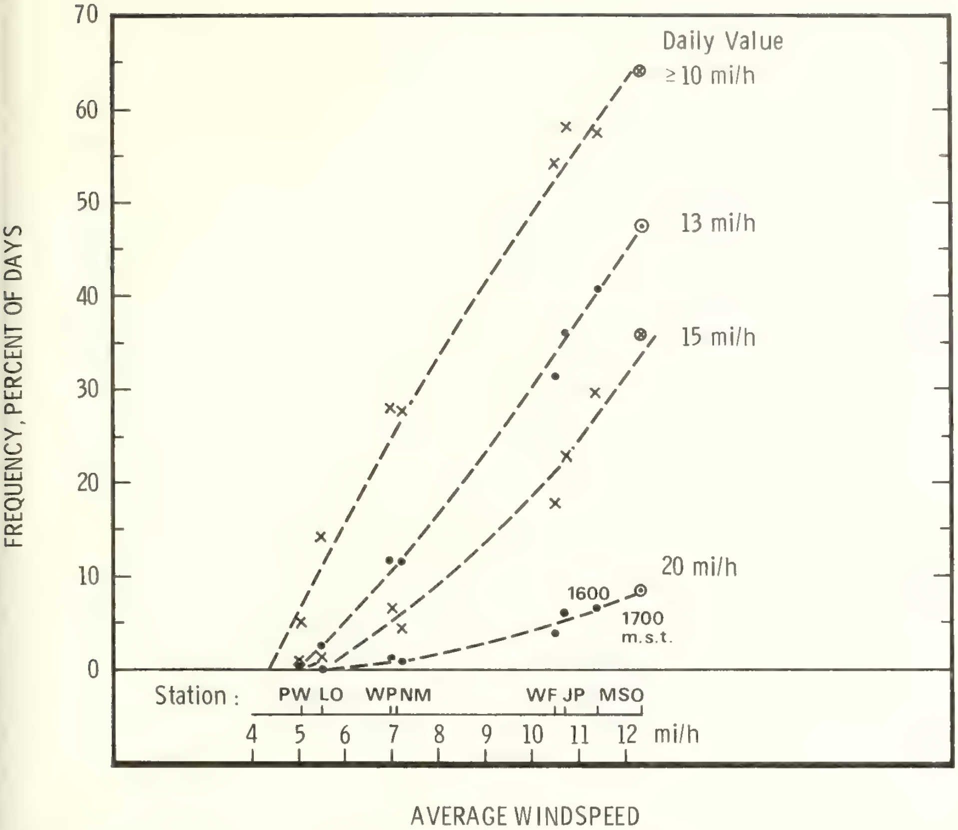


Figure 16.—"Frequency-versus-average" relationships (see fig. 8) for windspeed at 16 m.s.t., except as noted, July-August; Howard Creek drainage vicinity. Based mostly on 10 to 17 years during 1954-70.

COMBINED FIRE-WEATHER ELEMENTS, FREQUENCY DISTRIBUTIONS

Ten-day frequencies of various combinations of afternoon temperature (dry bulb), relative humidity, and windspeed can be obtained from summaries such as table 14 (appendix). The frequencies (or probabilities) can also be obtained from graphs, with their possibly easier and broader use, as follows.

Temperature and Relative Humidity

For joint probabilities involving these two elements, the procedure first obtains the frequency of the specified dry bulb alone (fig. 12, upper panel). This frequency is then multiplied by that of having the specified relative humidity when given the same dry bulb.

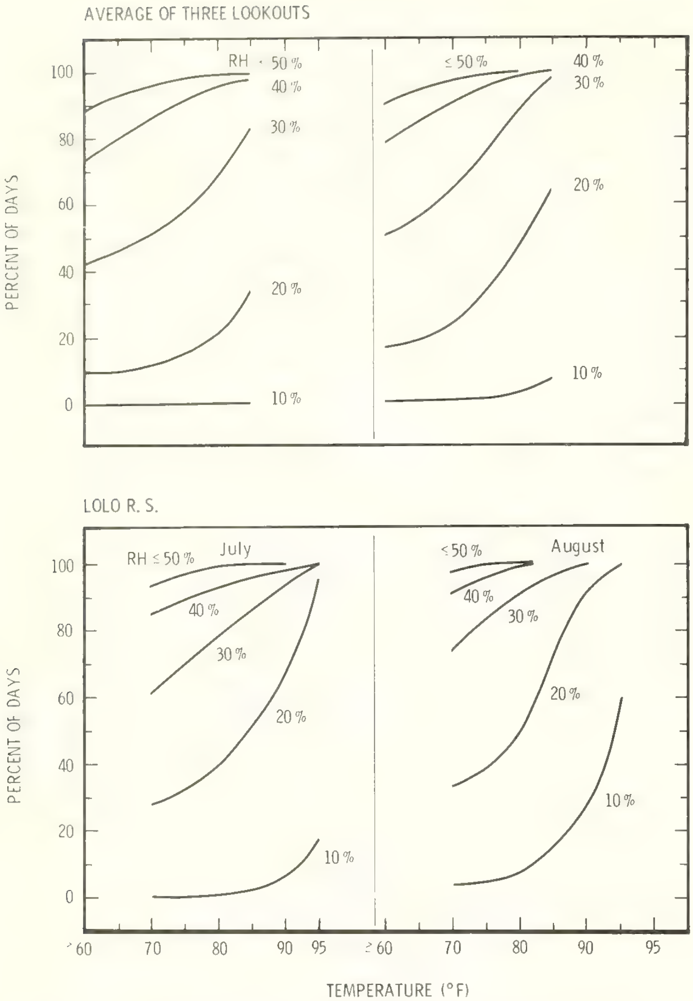


Figure 17.—Percentage frequency of July and August days with relative humidity reaching specified values at 1600 m.s.t., for a given dry bulb temperature threshold; Howard Creek drainage vicinity.

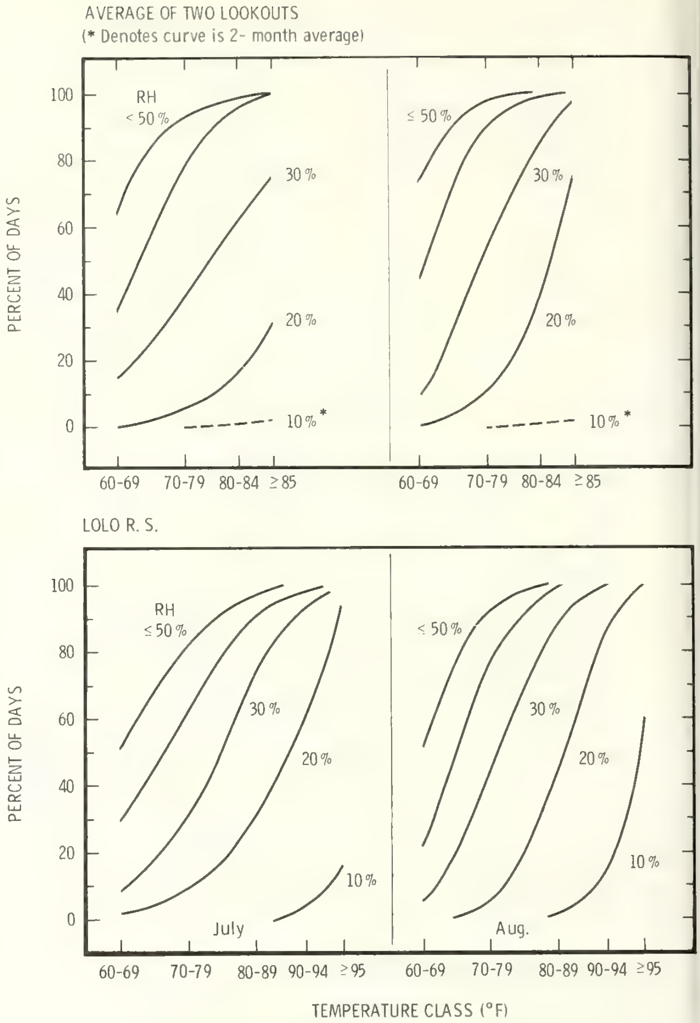


Figure 18.—Percentage frequency of July and August days with relative humidity reaching specified values at 1600 m.s.t., for a given dry bulb temperature range (class); Howard Creek drainage vicinity.

Graphs for the second step, if drawn manually, proceed from the monthly frequencies in table 14 (appendix); the frequencies are accumulated, without respect to windspeed, in descending order of dry bulb value and ascending order of relative humidity. The two elements may be treated in terms of threshold values (fig. 17) or as values within certain ranges (fig. 18). While the graphs of these two types are monthly, they do allow estimates of 10-day joint probabilities, since the first step (using fig. 12) does distinguish 10-day periods. For this step, the dry bulb frequency may, alternatively, be obtained from an "F-A" graph (fig. 13). The starting point would then be the 10-day average dry bulb (as from fig. 10).

The graph operation, with alternate first step, is illustrated in figures 19 and 20. These reproduce in simpler form some of the above-mentioned figures. As an example, using figure 19, we may seek the probability of a midafternoon dry bulb (DB) ≥ 80° F (27° C) combined with a relative humidity (RH) ≤ 20 percent during August 11-20 at the canyon location in figure 10. The latter figure shows the 10-day average DB to be about 78.0° F (25.5° C). Entering panel A, figure 19, at this value, the frequency of a DB ≥ 80° F is found, following the projected lines and arrows, to be 53 percent. In this case, the same result could have been obtained directly from a frequency graph of the type shown in figure 12.

Panel B, figure 19, is then entered at the 80° F threshold; as shown by the projected lines, the probability of an accompanying RH ≤ 20 percent is 49 percent. The joint probability of these DB and RH values is thus the multiplication product of 53 percent and 49 percent, divided by 100 percent; this gives 26 percent.

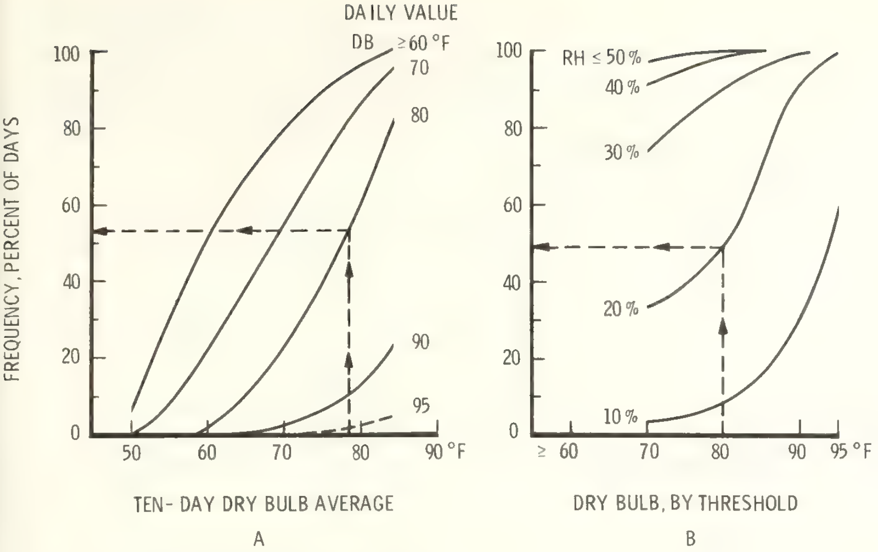


Figure 19.—Illustration of steps in graph estimation of joint frequency of specified dry bulb (DB) and relative humidity (RH) threshold values. First step uses panel A (similar to fig. 13) to obtain frequency of DB. Second step uses panel B (similar to fig. 17) to obtain frequency of RH. Result, in percent, is multiplication product of these two frequencies divided by 100 percent.

As an example using figure 20, the desired conditions may be midafternoon DB between 60° and 79° F (15.5° and 26° C) and RH between 31 and 40 percent during August 21–31 at the ridge elevation in figure 10. To find the probabilities from figure 20, the percentage-frequency interval between limiting curves is used. This particular calculation is done in two segments to correspond with the DB class intervals in panel B.

Thus entering panel A, figure 20, at an average DB of 69° F (20.5° C) (from fig. 10), the projected lines show that the probability of a DB within the 60° to 69° F range is 30 percent—this is the difference between the probabilities of ≥60° F and ≥70° F, which are, respectively, 81 percent and 51 percent. In a like manner, the probability of 70° to 79° F is found to be 39 percent (51 percent minus 12 percent).

As shown by the projected lines in panel B, figure 20, the probabilities of an accompanying RH between 31 and 40 percent (or between ≤30 and ≤40 percent) are 32 percent (42 percent minus 10 percent) for 60° to 69° F and 38 percent (90 percent minus 52 percent) for 70° to 79° F. The estimated joint probability is, therefore, $[(30 \times 32) + (39 \times 38)]$, divided by 100, or 24 percent.

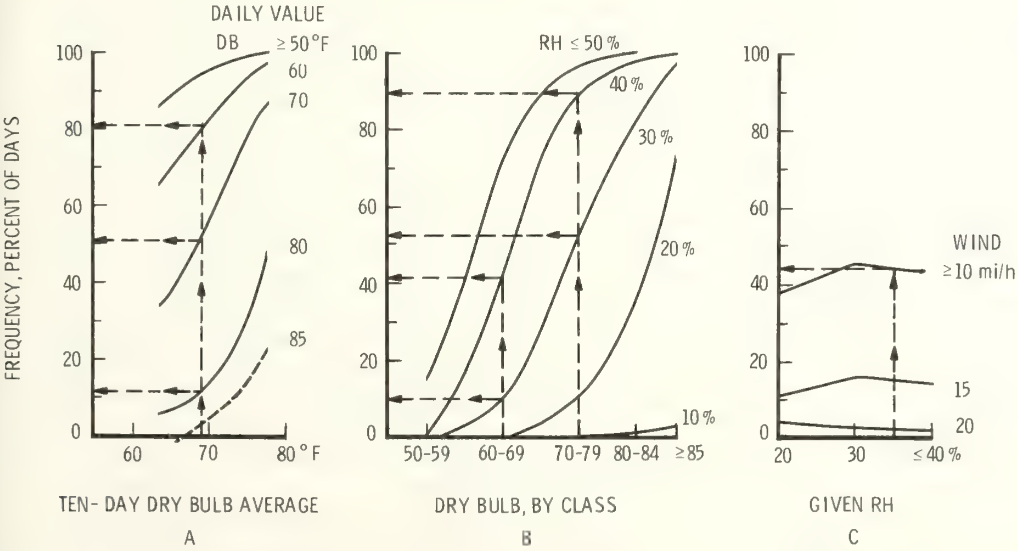


Figure 20.—Illustration of steps in graph estimation of joint frequency of dry bulb (DB) and relative humidity (RH) values within specified ranges; also for three-way frequency including windspeed. Procedure is analagous to that in figure 19, except panel B is similar to figure 18; panel C gives frequency of specified windspeeds.

Temperature, Relative Humidity, and Windspeed

The three-way probability may be estimated by multiplying the joint DB-RH probability by that for windspeed alone (as from fig. 16), then dividing by 100 percent. This simplification is valid where there is little correlation of the windspeed frequencies with DB and RH (as is found in the Northern Rockies).

Where there may be some correlation with RH (but little, if any, with DB), a graph is added as in panel C, figure 20. This plots the frequency of days with various windspeeds against given values of relative humidity. The windspeed probability obtained from such a graph is then multiplied by the DB-RH probability.

Panel C (which actually appears unnecessary in this case) indicates that for RH between 31 and 40 percent, the frequency of a windspeed ≥ 10 mi/h (16 km/h) is 44 percent. Thus, if a speed of < 10 mi/h is desired on the ridge (fig. 10), together with the previously specified DB and RH ranges, the three-way probability is the previously obtained 24 percent multiplied by 56 percent, divided by 100 percent. This gives a result of 13 percent.

SUNSHINE; SOLAR RADIATION

Sunshine Duration

Units, number of hours or percentage of maximum possible hours. The sunshine data are from first-order (now mostly airport) stations and have been summarized in NOAA (1971). Approximations for other locales can be made from maps in ESSA (1968). These maps attempt some adjustment in mountain areas, where less sunshine may be implied from generally greater cloudiness and precipitation.

Average number of hours, monthly and annual.—This type of data gives a direct measure of sunshine duration. The monthly aggregate will depend on length of daylight—varying with season and latitude, as well as cloudiness. Durations will be reduced in valley and canyon locations having shading by nearby terrain.

Average percentage of maximum possible hours.—These data are more widely published than the number of hours. The percentage values give a less direct measure of sunshine duration; but, since they do not depend on length of daylight, they more readily depict a month's generally clear or cloudy character.

Incoming Radiation

Units (of published data), langleys, defined as gram-calories per square centimeter. This is the solar radiation received at a surface location. It includes direct and diffuse (or scattered) radiation (Schroeder and Buck 1970). For conversion to units of watt-hours per square meter, the numbers of langleys are multiplied by 0.0861.

Average daily total, by months.—The published data refer to the radiation upon a horizontal surface and are from a limited number of stations, mostly at airports and agricultural experiment stations. (Publication, in "Climatological Data, National Summary" ceased in 1977.) As with sunshine duration, approximations for other locales are afforded by maps in ESSA (1968). Another set of maps, shown in part by Bryson and Hare (1974), includes radiation data estimated from relationships with observed sunshine or cloud cover and station elevation; the resulting depiction for Pacific coastal areas appears to be more realistic.

In mountain areas, radiation totals will generally increase with elevation, but other influences can be much greater—particularly in winter. Factors include slope aspect and angle (Geiger 1965; Reifsnyder and Lull 1965) and shading by terrain, as in deep valleys or canyons (Barry 1981).

POTENTIAL EVAPOTRANSPIRATION

Units, inches, or millimeters. Potential evapotranspiration (PET), from soil and vegetation surfaces, is the combined evaporation and transpiration possible when there is an adequate moisture supply at all times. Actual evapotranspiration during the year (or warm season) will generally be less. Calculated monthly values of these two quantities, together with other data pertaining to climatic water balances, are listed for many locations in the United States by Thornthwaite Associates (1964). The PET values are based on the Thornthwaite method (Oliver 1973); they may tend to be underestimated (Sellers 1965).

PET can also be calculated by use of a ratio applied to averages of data from standard, "Class A" evaporation pans. Estimates for annual and warm-season PET totals are provided by maps in ESSA (1968), based on 1946–1955 data. The ratio shown is near 0.70 in the western United States and 0.75 to 0.80 in eastern portions. Additional evaporation pan data may be obtained from U.S. Weather Bureau (1964–1965) and annual "Climatological Data," State summaries. This method is generally not reliable for estimates of average monthly PET totals.

DETAILS OF DATA CONSIDERATIONS, TREATMENT, AND ADJUSTMENT METHODS

Detection and Treatment of Errors and Missing Data; Additional Considerations

ERRORS

The published climatological data contain occasional errors or omissions (of daily precipitation amounts), aside from the designated missing data, but are in generally reliable condition.

The observations entered onto the Fire-Weather Data Library tapes at Fort Collins, Colo., undergo a screening program, which, however, has rather loose criteria. For example, dry bulb temperatures are accepted between -99° and +136° F (-73° and +58° C); dewpoint and minimum temperatures between -99° F and the present dry bulb (Furman and Brink 1975). Relative humidity (computed from the dry bulb and wet bulb readings) is accepted as low as 1 percent (formerly, 0 percent); windspeed as high as 99 mi/h (159 km/h); 24-hour precipitation as high as 9.99 inches (254 mm). Large errors may thus pass through the screening. Some of these errors arise in the original observations, but the majority can be traced to later processing. Errors also arise in arbitrary, fill-in values given to missing data for continuity in computing fire-danger indexes. These values commonly repeat those observed on preceding or succeeding days.

Further data screening, by the user, may thus be advisable; this has been done through 1980 at the Northern Forest Fire Laboratory for all of the Forest Service Region 1 stations. For such action, the first step is to obtain a data printout from the tapes at Fort Collins. A visual scanning can then detect highly unlikely values. Reasonable or acceptable values may vary with

the region or location, as well as portion of the fire season. The user should also examine the final output tables and statistics. Where the resources are available, the suspected errors can be confirmed and corrected by checking the original observation forms (or similar information published in monthly "Climatological Data," State summaries). Otherwise, the data can be treated as missing and estimates possibly made. Smaller, less obvious errors that escape may be tolerated, particularly if they tend to cancel one another.

MISSING DATA

Occasional days with missing data will generally have little effect on the overall statistics of elements such as temperature, relative humidity, and wind; there is a risk that extreme values will be missed. The effect can be more serious with precipitation, leading to a bias toward lower totals. A bias can also occur in temperature and humidity, as at lookout stations in the Northern Rockies. The missing data are concentrated in early and late season of usual operation, mostly in years when the lookouts are down due to cool, moist weather.

To remove these biases, estimates can be made for the daily values, or adjustments made to the 10-day or monthly averages or totals, based on comparisons with other stations. In standard climatological practice, the calculations use the "ratio method" for precipitation and the "difference method" for temperature and relative humidity, explained later.

As mentioned above, missing data may have been given fill-in values—often quite poor—for continuity in computing fire-danger indexes. When these cases are detected, as through checking data printout or original forms, the values can be replaced by more careful estimates (aided by surrounding station data) or relegated to blanks. For inclusion in the computed averages or totals, an individual 10-day period or month should have at least a specified number of observations; thus, too many blanks are to be avoided. (At the same time, erroneous data may be worse than no data at all.)

The NOAA, Environmental Data Service, computes monthly averages of daily maximum and minimum temperatures at its cooperative stations with as many as 9 days missing. These days can be consecutive or spread throughout the month; the averages will tend to be less reliable in the former case. For precipitation, prior to 1982, a monthly total was published as a blank in "Climatological Data," State summaries, when only a single daily measurement was missing. The complete monthly total was usually estimated later, in the annual issue of this publication.

In summarizing fire-weather data, the number of days required in a 10- (or 11-) day period might be set at 8 for precipitation. The rationale is that amounts on 1 or 2 missing days (as on weekends) may be included in the next day's measurement. This is not, however, true with the more recent AFFIRMS data. If possible, estimates should be made for the missing days, or 3-day totals apportioned to the individual days. The minimum acceptable number of days for temperature and relative humidity is suggested as 6 (if no estimates are made for missing days).

STATION LOCATION CHANGES

Changes in station location or exposure can adversely affect the data homogeneity and thus the comparability with past averages. This problem occurs mainly in the climatological station network, which provides year-round details. Change in daily observation time may also be serious, as discussed below. Testing of a station's record for homogeneity is a subject beyond the scope of this guide. (Methods or formulas are described by Landsberg 1958; Conrad and Pollak 1962; Oliver 1973.)

In general, when climatological data are used and there is a choice of stations, those selected should have a history of little or no change. Location and exposure changes through the mid-1950's are documented in U.S. Weather Bureau (1956–58). Less detailed documentation is given in U.S. Weather Bureau (1954–58; 1964–65). Later changes were, until 1973, listed in annual "Climatological Data," State summaries. Histories of first-order (mostly airport) stations are included in the annual issues of "Local Climatological Data." Around 1960, many of these stations underwent a change from roof to ground exposure of temperature and humidity instruments (in a change to remote, electronic equipment placed on the airfields). Their published temperature normals are adjusted to the present exposure.

OBSERVATION TIME

Differences or changes in daily observation time can be serious with respect to afternoon fire-weather data (discussed under the next heading), as well as daily maximum and minimum temperatures and the derivative monthly means. The effect on these temperatures has been described by Rumbaugh (1934); Baker (1975).

Maximum and minimum temperatures at many cooperative stations are based on a 24-hour period ending at 4 or 5 p.m. local time. This was also the case at fire-weather stations in the Northern Rockies prior to 1974. With such a dividing hour, the recorded 24-hour maximum may occasionally be 10° F (6° C) or more higher than the current day's actual maximum. The resulting monthly average maximums may be 2° F (1° C) higher than those based on the calendar day (midnight to midnight)—the 24-hour period used at the official airport stations—or on an early morning (7 or 8 a.m.) observation time, used at other cooperative stations. Such a difference occurs in the Northern Rockies in spring and summer months; about 1.0° F (0.5° C) difference in autumn and winter. Minimum temperatures read in the afternoon are generally well representative of actual overnight minimums, but may average close to 1.0° F higher than those for the calendar day. They may average 2.0° F higher in autumn and winter than minimums read in early morning.

Baker (1975) shows that monthly means based on calendar-day maximum and minimum temperatures are similar to the "true" mean obtained by averaging temperatures observed at each hour of the day. By this standard, the monthly means based on midafternoon readings can be 1.0° to 1.5° F too high during most of the year. Close comparisons should use stations having similar observation times (as listed in monthly 'Climatological Data," State summaries) or should make allowances for differing times.

Techniques for Adjusting or Extrapolating Climatic Data

ADJUSTMENT FOR CHANGE IN FIRE-WEATHER OBSERVATION TIME

A 3-hour change in fire-weather observation time, made at Forest Service Region 1 stations in 1974, has brought changes of up to 3° F (2° C) in average observed dry bulb; as much as 3 to 5 percent in average relative humidity. In such cases, for

present applications, the older, longer-based averages should be adjusted to the current observation time. Frequency distributions can then be adjusted by use of previously described frequency-versus-average graphs, which are entered at the revised average values.

For adjusting the averages, differences between the present and former observation times may be evaluated from hygrothermograph traces covering several years. Another procedure, not requiring such traces, makes a comparison with an adjacent airport station for which hourly data have been summarized. Data at the two stations are compared for several years at the former fire-weather observation time and for several years at the new time. The net change in average difference between the two stations is then added to (or subtracted from) the difference readily calculated for the airport. This method depends on there being no change in instrument exposure or accuracy at either station.

As an example of the adjustment in frequency distribution, assume that the canyon location in figure 10 has a 1300–1600 m.s.t. difference in DB averaging -3° F; RH, +3 percent. The estimated 1300 DB and RH during August 1-10 thus average 77°F (25°C) and 33 percent. Applying these averages to figures 13 and 14, respectively, the frequency of a 1300 DB $\geq$90° F (32° C) is 8 percent, compared with 12 percent at 1600 (when the average DB is 80° F [27° C]); frequency of a 1300 RH $<$20 percent is 20 percent, compared with 28 percent at 1600 (when the average RH is 30 percent). Combined frequencies are likewise affected.

SMOOTHING

Smoothing of 10-day averages and frequency distributions is suggested, particularly when these are based on relatively short periods of record—for example, less than 20 years for temperature and relative humidity and less than 30 years for precipitation. The smoothing seeks to reduce accidental irregularities, which are apt to be greater in a smaller data sample. The process averages in values of preceding and succeeding 10-day periods. To avoid oversmoothing, which may obscure true characteristics, weighting is used; this gives greatest weight to the central, initially calculated 10-day value. A common form of weighting applies factors of 1, 4, and 1, respectively, to three consecutive 10-day values.

To illustrate this "three-point" smoothing, we will use a 14-year record that gives the following midafternoon dry bulb averages (in °F) for successive 10- (or 11-) day periods from July 1-10 through September 1-10:

77.7, 83.5, 84.9, 82.8, 83.3, 75.4, and 73.4.

To calculate the smoothed average for August 1-10, which has an initial value of 82.8, the arithmetic is:

$[(1 \times 84.9) + (4 \times 82.8) + (1 \times 83.3)]$, divided by 6—the total number of weights.

This gives an average of 83.2. Similarly, the smoothed average for August 11-20 is calculated as 81.9; that for August 21-31, 76.3. Further examples and comments are given later in this section.

CALCULATION OF NORMALS FROM SHORT-RECORD AVERAGES

Precipitation: Ratio Method

Given: Station "X" with August rainfall average based on 13 years, 1967–79.

Adjacent stations on two (or preferably more) sides with published or available normal (1941-70 average) August rainfall, as well as averages based on 1967–79. These stations, climatological or fire-weather, ideally should have undergone little or no change in site or exposure (or surroundings) during the entire period. Use of several stations tends to reduce the error that may result with any one station.

Steps: The general formula for computing the normal at station X is:

$$N_x = \frac{A_x}{n}\left(\frac{N_1}{A_1} + \frac{N_2}{A_2} + \ . \ . \ . + \frac{N_n}{A_n}\right),$$

where N is the normal and A is the short-period average; subscript x refers to the short-record station; and 1, 2, ..., n refer to the individual adjacent stations (n in number).

The method assumes that the 13-year ratio A_x/A_1 is a constant that will apply for 30 years; similarly for the ratio A_x/A_2. This, because of the large variability of precipitation, is not entirely true.

To illustrate the method, using actual data from the northern Idaho area, the 13-year August average rainfall at station X was 1.51 inches (38 mm). The 13-year averages at three surrounding stations were 1.36, 1.51, and 1.54 inches; their 30-year normals, 1.05, 1.06, and 1.33 inches, respectively. The estimated normal at station X is:

$$\frac{1.51}{3} \times \left(\frac{1.05}{1.36} + \frac{1.06}{1.51} + \frac{1.33}{1.54}\right), \text{ or 1.18 inches (30 mm).}$$

If only one adjacent station had been used, the result would have been 1.17, 1.06, or 1.30 inches, depending on the station.

To obtain a more stable ratio between stations, the precipitation during the short (13-year) period might have been summed over July and August combined, instead of only over a single month, or monthly ratios smoothed. We would not, however, advise applying the ratio of annual totals (if available) to estimate normals for individual months, because the actual ratio between two stations may vary considerably with the season. For estimates of 10-day normal rainfall, using the above formula, smoothing of at least the 10-day averages or ratios is advisable.

Temperature and Relative Humidity: Difference Method

Given: Station "X" with August average daily maximum temperatures based on 7 years, 1967–73.

Adjacent stations, as described for precipitation, with available normal (1941-70) August average daily maximums, as well as averages based on 1967–73.

Steps: The general formula for computing the normal at station X is:

$$N_x = A_x + \frac{1}{n}[(N_1 - A_1) + (N_2 - A_2) + . \ . \ . + (N_n - A_n)].$$

where notation is the same as before.

The method assumes that the 7-year differences $A_x - A_1$, $A_x - A_2$, etc., are constants that will apply for 30 years.

To illustrate the method, again using data from the northern Idaho area, the 7-year August average daily maximum at station X was 88.1° F (31.2° C). The 7-year averages at three surrounding stations were 82.5°, 85.8°, and 92.0° F; their 30-year normals, 79.5°, 82.3°, and 88.8° F, respectively. The estimated normal at station X is:

$$88.1 + \frac{1}{3}\,[(79.5 - 82.5) + (82.3 - 85.8) + (88.8 - 92.0)],$$

or 84.9° F (29.4° C).

If only one adjacent station had been used, the result would have been 85.2°, 84.6°, or 84.9° F, depending on the station. In this case, one may have sufficed.

ALTERNATE METHOD OF ADJUSTING AVERAGES AT A LOOKOUT STATION

As indicated earlier, lookouts tend to be manned for a shorter season in years when the fire danger is down. Thus, in the Northern Rocky Mountain area early July and late August data will often be missing. A nominal 1954–70 record at Williams Peak Lookout (appendix), contains 17 years of July 21–31 data, but only 6 usable years for July 1–10.

Without adjustment, the resulting climatic averages typically are biased toward warmer and drier conditions. Correct application of the adjustment methods just described uses ratios and differences based only on the specific years and days with data at all stations involved. The procedure can be laborious and the results still subject to error. The following, somewhat simpler method of adjustment may suffice. It still does require comparison with an adjacent station.

Temperature and Relative Humidity

Example for Williams Peak Lookout, Mont.

Given: 10-day average dry bulb temperature and relative humidity at 1600 m.s.t. at Williams Peak Lookout, July and August 1954–70; based on incomplete record, particularly for July 1–10 and August 21–31.

10-day average DB and RH at Ninemile Ranger Station (18 mi [30 km] east-northeast of Williams Peak) for same period as above; data complete.

Procedure: The step numbers correspond to the column numbers in table 2.

(1) and (2). Tabulate the 10- (or 11-) day average DB at Williams Peak and Ninemile, respectively.

(3). Subtract the column 2 averages from the column 1 averages. Smooth the differences in column 3 as follows (steps 4, 5, and 6):

Table 2.—Steps (described in text) for adjusting 10- (or 11-) day averages of afternoon temperature and relative humidity at a lookout station having incomplete data in early and late season; example for Williams Peak, using data from Ninemile Ranger Station (1954–1970)

Data period	Observed average			Smoothed difference		Assumed diff., end periods	Cols. 4,5,6	W. Pk. adjusted avg., col. 2 + col. 7	W. Pk. monthly avg., from col. 8	W. Pk. avg., using elaborate method
	W.Pk.	Nmi.	Diff., col. 1 - col. 2	3-period avg.	2-period avg.					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dry bulb temperature, °F										
10 days beginning:										
July 1	70.1	78.4	− 8.3			− 10.1	− 10.1	68.3		68.2
11	73.2	82.8	− 9.6		− 10.1		− 10.1	72.7		72.4
21	73.9	84.4	− 10.5	− 10.2			− 10.2	74.2		74.0
Aug 1	72.3	82.9	− 10.6	− 10.3			− 10.3	72.6		72.3
11	72.5	82.3	− 9.8		− 10.2		− 10.2	72.1		71.8
21	68.0	76.5	− 8.5			− 10.2	− 10.2	66.3		66.1
Month:										
July	73.0	81.9							71.8	71.6
Aug	71.2	80.4							70.2	69.9
Relative humidity, percent										
July 1	39.0	35.5	+ 3.5			+ 8.7	+ 8.7	44.2		42.2
11	37.9	31.0	+ 6.9		+ 8.7		+ 8.7	39.7		38.2
21	35.0	24.5	+ 10.5	+ 9.3			+ 9.3	33.8		33.1
Aug 1	37.1	26.7	+ 10.4	+ 10.2			+ 10.2	36.9		36.6
11	36.1	26.4	+ 9.7		+ 10.1		+ 10.1	36.5		36.8
21	40.7	33.3	+ 7.4			+ 10.1	+ 10.1	43.4		43.5
Month:										
July	37.0	30.1							39.1	37.7
Aug	38.2	28.9							39.1	39.1

(4). For the two central 10- (or 11-) day periods, July 21-31 and August 1-10, calculate average differences that include the immediately preceding and succeeding 10-day periods; equal weighting is used. Thus, in table 2 we have summed the July 11-20 (column 3) difference (-9.6), the July 21-31 difference (-10.5), and the August 1-10 difference (-10.6); then divided by 3, giving -10.2 in column 4 opposite July 21- 31. For August 1-10, the arithmetic starts with the July 21-31 difference.

(5). For July 11-20 and August 11-20, the smoothing omits July 1-10 and August 21-31, respectively (the two end periods with much missing data at Williams Peak). Thus, in table 2 only the July 21-31 (column 3) difference (-10.5) is added to the July 11-20 difference (-9.6); the sum is divided by 2, giving -10.1 in column 5 opposite July 11-20.

(6). For the two end periods, July 1-10 and August 21-31, disregard the differences in column 3. Instead, use the July 11-20 and August 11-20 values, respectively, which were calculated in step 5; that is, -10.1 and -10.2.[6]

(7). Combine the smoothed differences (columns 4, 5, and 6) into one column.

(8). Add the values in column 7 to the averages at Ninemile (column 2). We now have the adjusted averages for Williams Peak.

(9). Calculate the monthly averages as follows: Multiply the adjusted averages for each of the two 10-day periods by 10 and that of the 11-day (final) period by 11; obtain sum and divide by 31.

The 10-day and monthly averages adjusted by the more elaborate difference method are shown for comparison in column 10. It is not certain which set of averages is more correct.

This procedure is suitable also for maximum temperature, but not for minimum temperature. Lookout-ranger station differences in 10-day average minimum can show larger variation during the course of the fire season, with nighttime inversions less frequent during the cloudier, wetter portions. Also diurnal temperature ranges are smaller with the cloudy, moist weather. Thus, for adjusting the early- and late-season minimums at a lookout, a compromise solution might be to subtract one-half the amount that was subtracted from the corresponding average maximum or dry bulb (column 1 minus column 8 value).

Repeat the above steps for relative humidity; illustration is given in table 2, lower half.

Precipitation

A similar procedure may be used, calculating ratios instead of differences. The ratios of lookout/ranger station average precipitation for July 1-10 and August 21-31 are then assumed equal to the smoothed ratios obtained for July 11-20 and August 11-20, respectively. The lookout averages or normals should generally be higher than those in the adjacent valleys or canyons, though differences in summer may be small. For example, the lookout/ranger station ratios for July and August as a whole are mostly between 110 percent and 140 percent in the Northern Rocky Mountain area.

[6]Use of these values is more in line with indications given by five former year-round mountaintop or pass stations in the Northern Rockies-interior Northwest. Differences in monthly average maximum temperatures between these stations and adjacent valley stations in June are practically the same as or slightly greater than those in July (contrary to the trend in column 3, table 2); similarly for differences in September compared with those in August.

In applying the adjustment methods to lookouts in areas having a longer observation season, the smoothing of differences or ratios is the same in principle as that illustrated for July and August. The end periods (with much missing data), though different, are treated as above.

EXTRAPOLATION OF FIRE-WEATHER STATISTICS AT A VALLEY OR CANYON LOCATION

The following methods apply to stations in valleys or canyons having a shortened fire-weather observation season (and short period of record). They may also be used for estimates at locations having no observational data, using only the appropriate steps. The methods extrapolate for the complete fire season, given the necessary data from preferably two adjacent valley or canyon stations. Ideally, this data should cover at least 20 recent years for temperature and relative humidity (at an unchanged daily observation time); 30 years for precipitation. With such lengths not obtainable from the fire-weather data library, smoothing is employed to reduce expected accidental irregularities. The two stations should be on opposite sides of location "X", approximately equidistant and within 25 or 50 air miles (40 or 80 km). Elevations should not differ by more than 1,000 ft (300 m); ideally, that of location "X" is somewhere in the middle.

Examples for Lolo Ranger Station, Mont.
Precipitation

Given: 10-day average rainfall at Lolo Ranger Station for July and August only, 1954-67; averages for same period at Ninemile Ranger Station, Mont., and Powell Ranger Station, Idaho (located 22 or 23 air miles [38 km] north and southwest, respectively, of Lolo Ranger Station).

Full-season (May 11-October 20) 10-day average rainfall at Ninemile and Powell for 1954-70.

Procedure: The step numbers correspond to the column numbers in table 3.

(1). Tabulate the July and August 1954-67, 10- (or 11-) day averages at Lolo Ranger Station; also, by summation, the monthly totals and the 2-month (July and August) totals.

(2) and (3). Tabulate the July and August 1954-67, 10-day averages at Ninemile and Powell, respectively.

(4). Calculate, for each period, the arithmetic average of the amounts in columns 2 and 3; obtain, by summation, the monthly and 2-month average totals.

(5) and (6). Tabulate the full-season, 1954-70, 10-day average rainfall at Ninemile and Powell, respectively.

(7). Calculate, for each period, the arithmetic average of the amounts in columns 5 and 6.

(8). Smooth the column 7 averages, using a 1-4-1 weighting as described earlier. For the first and last 10-day periods (May 11-20 and October 11-20), however, the smoothed averages are obtained by only "two-point" weighting of 2-1 and 1-2, respectively.

Thus, for May 11-20 the calculation is [(2 × 0.670) + (1 × 0.710)], divided by 3; for May 21-31, [(1 × 0.670) + (4 × 0.710) + (1 × 0.919)], divided by 6. Done in overlapping sequence, the next calculation, for June 1-10, gives a weighting of 4 to the 0.919 value.

(9). The column 8 averages are adjusted to correct for the mixing of 10-day and 11-day precipitation amounts in the

Table 3.—Steps (described in text) for extrapolating 10- (or 11-) day average precipitation at a ranger station having a short fire-weather observation season; example for Lolo Ranger Station, using data from Ninemile and Powell Ranger Stations

Data period	Avg. precip., 1954-1967				Avg. precip., 1954-70			Smoothed avg.		Ratio,	Adjusted avg.	
	Lolo (1)	Nmi. (2)	Pow. (3)	Avg., cols. 2 & 3 (4)	Nmi. (5)	Pow. (6)	Avg., cols. 5 & 6 (7)	(See text) (8)	Adj. to 10 or 11 days (9)	col. 1 to col. 4 total, J + A (10)	Col. 10 ratio × col. 9 avg. (11)	Using col. 10 ratio of 0.851 (12)
	Inches											
10 days beginning:												
May 11					0.503	0.837	0.670	0.683	0.660			0.56
21					.529	.890	.710	.738	.762			.65
June 1					.829	1.009	.919	.857	.842			.71
11					.668	.840	.754	.799	.799		No adjustment required (see text)	.68
21					.645	1.075	.860	.780	.780			.66
July 1	0.526	0.503	0.610	0.557	.418	.558	.488	.523	.523			.45
11	.344	.289	.331	.310	.312	.339	.326	.331	.325			.28
21	.176	.146	.206	.176	.172	.218	.195	.234	.242			.21
Aug 1	.246	.374	.284	.329	.316	.278	.297	.286	.281			.24
11	.269	.144	.322	.233	.278	.390	.334	.379	.373			.32
21	.736	.620	.753	.687	.571	.712	.642	.567	.586			.50
Sept 1					.280	.720	.500	.589	.579			.49
11					.616	1.162	.889	.767	.767			.65
21					.364	.728	.546	.662	.662			.56
Oct 1					.559	1.237	.898	.831	.831			.71
11					.627	1.071	.849	.865	.865			.74
Month:												
July	1.046	.938	1.147	1.043								
Aug	1.251	1.138	1.359	1.249								
J + A	2.297			2.292						1.002		
Example (see text), if col. 1 values gave J + A total of 1.950:										.851		

smoothing process. For an overall correction, the value opposite May 11 in column 8 is multiplied by 0.967; the values opposite June 1, July 11, August 1, August 11, and September 1 are multiplied by 0.983; those opposite May 21, July 21, and August 21, by 1.033.

(10). Calculate the ratio of the 2-month total in column 1 to the 2-month total in column 4. If the ratio is between 0.905 and 1.095, the averages in column 9 can, arbitrarily, be used without further adjustment. If the ratio is beyond these limits (the difference in totals is 10 percent or greater), multiply each of the averages in column 9 by this ratio.

In the present example, the July and August total in column 1, namely 2.297, is practically identical to that in column 4, so no adjustment is made to the July 1-10 through August 21-31 averages in column 9. The earlier- and later-season averages in column 9 are also left as is, though errors of 10 percent or more may occur due to possible seasonal variation of the actual precipitation ratios. This seasonal variation is largely related to greater topographic effects outside the summer months; it precludes attempts to extrapolate the average precipitation at mountain locations from valley data.

If, instead, the amounts in column 1 gave a July-August total of 1.950, the column 1/column 4 ratio would be 0.851 and adjustments made. The column 9 average for each July and August period is multiplied by 0.851. The same ratio is applied to the earlier- and later-season averages in column 9, though with the risk mentioned above.

In figure 7, the estimated averages during September and October were, in fact, lowered by as much as 17 percent from those in table 3 (column 9) on the basis of additional information—the average monthly precipitation at a nearby climatological station.

Having obtained the 10-day averages, the probabilities of particular daily amounts can be approximated from the type of graph illustrated in figure 8. To construct such a graph, the observed percentage frequencies during each 10-day period are plotted against the corresponding average rainfall; these averages are based on the actual station record. The two adjacent stations, with longer records and full-season data, are included in the same graph. These will provide more points from which generalized, average curves for an area can be drawn.

Afternoon Dry Bulb and Relative Humidity

Given: 10-day average DB and RH at 1600 m.s.t. at Lolo Ranger Station for July and August, 1954–67, and for September 1–10 during 10 of these years; averages for same periods at the Ninemile and Powell Ranger Stations.

Full-season (May 11-October 20) 10-day averages of DB and RH at Ninemile and Powell for 1954–70.

Procedure, example for DB: The step numbers correspond to the column numbers in table 4.

(1) and (2). Tabulate the full-season, 1954–70, 10-day averages of DB at Ninemile and Powell, respectively.

(3), (4), and (5). Tabulate the short-season, 1954–67, 10-day averages at Ninemile, Powell, and Lolo Ranger Stations, respectively.

(6) and (7). Obtain differences between the two periods; subtract the 1954–67 averages at Ninemile and Powell from their respective 1954–70 averages.

(8). Calculate arithmetic averages of the values in columns 6 and 7.

(9). Add the differences in column 8 to the corresponding 10-day averages at Lolo Ranger Station in column 5. Resulting values are the estimated, unsmoothed 1954–70 averages at this location.

(10). Subtract the July 21–31 DB average at Ninemile in column 1 from each of the other averages in column 1.

(11) and (12). Do the same for Powell (using the averages in column 2) and for Lolo Ranger Station (using the averages in column 9).

Table 4.—Steps (described in text) for extrapolating 10- (or 11-) day averages of afternoon temperature at a station as in table 3; example for Lolo Ranger Station

Data period	Avg., 1954-1970 Nmi. (1)	Avg., 1954-1970 Pow. (2)	Avg., 1954-1970 Lolo (adj) col. 5 + col. 8 (9)	Difference, 10-day avg. minus July 21-31 avg. Nmi. (10)	Difference Pow. (11)	Difference Lolo (12)	Avg., cols. 10 & 11 (13)	Smoothed diff. (see text) (14)	Est. avg. at Lolo., July 21-31 avg. in col. 9 + col. 14 (15)
	Dry bulb temperature, °F								
10 days beginning:									
May 11	63.0	60.9		-21.4	-21.6		-21.5	-21.5	60.0
21	65.4	63.3		-19.0	-19.2		-19.1	-19.0	62.5
June 1	68.2	66.8		-16.2	-15.7		-16.0	-16.2	65.3
11	70.0	69.8		-14.4	-12.7		-13.6	-13.7	67.8
21	72.3	70.6		-12.1	-11.9		-12.0	-11.3	70.2
July 1	78.4	77.4	75.5	- 6.0	- 5.1	- 6.0		- 6.3	75.2
11	82.7	81.7	80.0	- 1.7	- 0.8	- 1.5		- 2.0	79.5
21	84.4	82.5	81.5	0	0	0		- 0.5	81.0
Aug 1	82.9	81.4	80.1	- 1.5	- 1.1	- 1.4		- 1.4	80.1
11	82.3	80.0	78.8	- 2.1	- 2.5	- 2.7		- 3.4	78.1
21	76.5	74.2	73.4	- 7.9	- 8.3	- 8.1		- 7.6	73.9
Sept 1	74.2	72.3	71.3	-10.2	-10.2	-10.2		-11.1	70.4
11	67.5	64.0		-16.9	-18.5		-17.7	-16.9	64.6
21	65.3	61.4		-19.1	-21.1		-20.1	-20.8	60.7
Oct 1	59.1	55.1		-25.3	-27.4		-26.4	-26.2	55.3
11	54.4	50.0		-30.0	-32.5		-31.3	-31.3	50.2

Data period	Avg., 1954-1967 Nmi. (3)	Avg., 1954-1967 Pow. (4)	Avg., 1954-1967 Lolo (5)	Difference in average, 1954-70 and 1954-67 Col. 1- col. 3 (6)	Col. 2- col. 4 (7)	Avg., cols. 6 & 7 (8)
	Dry bulb temperature, °F					
July 1	77.7	76.3	74.6	+0.7	+1.1	+0.9
11	83.5	82.2	80.7	−0.8	−0.5	−0.7
21	84.9	82.7	81.9	−0.5	−0.2	−0.4
Aug 1	82.8	81.4	80.0	+0.1	0	+0.1
11	83.3	80.9	79.8	−1.0	−0.9	−1.0
21	75.4	72.8	72.1	+1.1	+1.4	+1.3
Sept 1 (10 yr)	74.4	72.2	71.4	−0.2	+0.1	−0.1

(13). Calculate arithmetic averages of the values in columns 10 and 11 for the 10-day periods not included in column 12.

(14). Smooth the combined column 12 and 13 values by use of 1-4-1 weighting as described earlier. For the first and last 10-day periods, however, leave the values as they are.

(15). For each 10-day period, add the corresponding difference in column 14 to the July 21-31 average at Lolo Ranger Station shown in column 9. The estimated, smoothed averages for the full season are thus obtained.

Derive the relative humidity averages in a similar manner, as illustrated in table 5.

In figure 10, the estimated September and October RH averages were lowered by as much as 4 percent, giving more weight to the Ninemile values in column 10 (table 5) than to those at Powell in column 11, which appear less representative in late season. (This was based on further comparison with another station.)

If the 10-day averages are to be estimated for a location having no past data, only the above steps (columns) 1 and 2 are used. A third step calculates an arithmetic average of the column 1 and 2 values. A fourth step smooths these averages, using 1-4-1 weighting as in the above step 14. The resulting estimates may require adjustment for elevation differences (which generally should not exceed 1,000 ft [300 m]). As an overall rule, for each 300-foot difference from the average elevation of the two adjacent stations, add or subtract 1.0° F for DB (assuming a higher value at the lower elevation) and 1 percent for RH (assuming a higher value at the higher elevation).

Having obtained the 10-day DB and RH averages, the probabilities of particular daily readings can be approximated from the types of graph illustrated in figures 13 and 14.

Table 5.—Steps, as in table 4, for extrapolating afternoon relative humitity; example for Lolo Ranger Station

Data period	Avg., 1954-1970 Nmi. (1)	Pow. (2)	Lolo (adj) col. 5 + col. 8 (9)	Difference, 10-day avg. minus July 21-31 avg. Nmi. (10)	Pow. (11)	Lolo (12)	Avg., cols. 10 & 11 (13)	Smoothed diff. (see text) (14)	Est. avg. at Lolo., July 21-31 avg. in col. 9 + col. 14 (15)
	Relative humidity, percent								
10 days beginning:									
May 11	45.0	44.9		+20.4	+17.1		+18.8	+18.8	46.5
21	46.3	46.8		+21.7	+19.0		+20.4	+20.3	48.0
June 1	47.3	47.2		+22.7	+19.4		+21.1	+20.8	48.5
11	48.6	43.4		+24.0	+15.6		+19.8	+19.4	47.1
21	42.1	42.3		+17.5	+14.5		+16.0	+15.5	43.2
July 1	35.4	34.9	36.9	+10.8	+7.1	+9.2		+9.7	37.4
11	31.0	31.0	32.9	+6.4	+3.2	+5.2		+5.0	32.7
21	24.6	27.8	27.7	0	0	0		+1.3	29.0
Aug 1	26.7	30.4	30.3	+2.1	+2.6	+2.6		+2.2	29.9
11	26.4	30.5	30.3	+1.8	+2.7	+2.6		+3.7	31.4
21	33.3	39.1	36.7	+8.7	+11.3	+9.0		+8.0	35.7
Sept 1	32.9	38.4	36.9	+8.3	+10.6	+9.2		+11.0	38.7
11	42.0	50.9		+17.4	+23.1		+20.3	+18.7	46.4
21	41.6	54.8		+17.0	+27.0		+22.0	+23.3	51.0
Oct 1	49.5	65.4		+24.9	+37.6		+31.3	+30.8	58.5
11	54.6	72.4		+30.0	+44.6		+37.3	+37.3	65.0

Data period	Avg., 1954-1967 Nmi. (3)	Pow. (4)	Lolo (5)	Difference in average, 1954-70 and 1954-67 Col. 1-col. 3 (6)	Col. 2-col. 4 (7)	Avg., cols. 6 & 7 (8)
	Relative humidity, percent					
July 1	36.4	36.7	38.3	−1.0	−1.8	−1.4
11	31.3	31.2	33.2	−0.3	−0.2	−0.3
21	24.7	28.1	27.9	−0.1	−0.3	−0.2
Aug 1	27.5	30.4	30.7	−0.8	0	−0.4
11	25.4	29.1	29.1	+1.0	+1.4	+1.2
21	35.5	41.4	39.0	−2.2	−2.3	−2.3
Sept 1 (10 yr)	31.1	36.5	35.0	+1.8	+1.9	+1.9

CONCLUSION

An area's climate can be described using the outline and methods contained in this guide. For many purposes in forest and rangeland management and research, fire-weather records may provide an adequate data base. Such records back to the 1950's or 1960's, together with programs for summarizing the data (Bradshaw 1981), are available through offices having access to the USDA computer at Fort Collins, Colo. The summary tables include averages and frequency distributions. Where further detail and year-round information are needed, climatic data can be obtained from various publications that are identified.

Potential problems in using the acquired data have been discussed. These pertain to lengths of record, errors, missing data, and changes in station site and observation time. For climatic statistics, particularly with 10-day resolution, at least 15 to 20 years of data are desirable; smoothing, as illustrated, can be used to reduce accidental irregularities. A station record of 30 years (the standard "normal" period) is recommended for precipitation. Methods have been presented for adjusting averages and frequencies (or probabilities) that are based on short records.

The various climatic elements or items have been listed and discussed. Some details and examples are given as to their presentation (in tables, graphs, and maps), together with interpretative comments; these may help toward making extrapolations or inferences about numerical values at other locations or times of day.

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APPENDIX
Examples of Computer Output, Tables 6 through 14

PRECIPITATION BY 10 (OR 11)-DAY AND MONTHLY PERIODS

STATION NUMBER 241507 NINEMILE RS YRS 1954-1970

PERIOD BEGINS	NO. YRS	MEAN TOTAL	STD DEV	MEDIAN	HIGHEST TOT.	YR	LOWEST TOT.	YR	EXTREME	YR	AVG MAX	STD DEV	MEDIAN
	10-DAY AND MONTHLY TOTALS								MAXIMUM DAILY TOTALS				
MAY 11	16	.503	.442	.415	1.40	57	0.00	66	.83	59	.335	.271	.315
MAY 21	16	.529	.383	.475	1.39	61	.02	63	1.00	61	.326	.229	.285
JUN 1	17	.829	.647	.890	2.19	64	0.00	69	1.00	64	.401	.310	.320
JUN 11	17	.668	.443	.570	1.95	65	.13	59	1.29	65	.389	.277	.360
JUN 21	17	.645	.946	.570	4.04	69	0.00	61	1.60	69	.336	.415	.250
JUL 1	17	.418	.375	.450	1.05	56	0.00	70	.87	56	.275	.266	.210
JUL 11	17	.312	.442	.130	1.52	65	0.00	61	1.47	65	.260	.391	.100
JUL 21	17	.172	.226	.130	.89	70	0.00	69	.47	70	.135	.154	.080
AUG 1	17	.314	.460	.060	1.44	63	0.00	69	1.44	63	.242	.389	.060
AUG 11	17	.278	.639	.030	2.65	68	0.00	70	1.20	68	.166	.299	.030
AUG 21	17	.571	.498	.390	1.63	65	0.00	69	1.10	66	.350	.315	.250
SEP 1	17	.280	.289	.300	.80	61	0.00	69	.44	65	.192	.194	.220
SEP 11	17	.616	.573	.380	1.99	68	.01	56	1.00	65	.356	.287	.280
SEP 21	17	.364	.352	.270	1.42	59	0.00	57	.78	59	.249	.217	.240
OCT 1	15	.559	.295	.570	.98	62	.01	56	.70	66	.325	.189	.300
OCT 11	13	.627	.524	.530	1.74	62	0.00	69	1.05	59	.375	.292	.390
MONTH													
JUN	17	2.142	.968	2.350	4.52	69	.54	61	1.60	69	.688	.380	.630
JUL	17	.902	.803	.850	2.93	65	.08	59	1.47	65	.421	.393	.340
AUG	17	1.162	.955	.850	3.50	68	0.00	55	1.44	63	.528	.433	.420
SEP	17	1.261	.867	.940	3.23	59	.30	66	1.00	65	.456	.225	.430

Table 6.—Precipitation: mean, median, and extreme totals (inches).

PRECIPITATION - PERCENT FREQUENCY OF DAILY AMOUNTS (INCHES)

- GIVEN TO NEAREST TENTH PERCENT. DECIMAL POINT OMITTED

STATION NUMBER 241507 NINEMILE RS 1954-1970

PERIOD BEGINS	TOTAL NUM. DAYS	TR	≥ .01	> .05	≥ .10	≥ .20	≥ .30	≥ .40	≥ .50	≥ .60	≥ .80	≥1.00	≥1.50	≥2.00	≥3.00	≥4.00
MAY 11	159	157	277	201	145	75	57	50	44	19	6					
MAY 21	179	140	324	229	179	101	56	28	11	11	6	6				
JUN 1	170	59	400	288	206	141	106	71	53	35	18	5				
JUN 11	170	112	347	259	194	135	76	41	18	12	6	5				
JUN 21	170	100	347	235	165	112	47	35	29	24	18	19	6			
JUL 1	170	124	247	153	112	76	47	35	18	12	6					
JUL 11	170	100	159	100	71	41	29	12	12	12	12	6				
JUL 21	187	75	119	70	53	32	21	5								
AUG 1	170	47	147	112	71	35	24	24	12	12	12	6				
AUG 11	170	94	141	112	76	53	29	18	12	6	6	6				
AUG 21	186	134	247	177	145	81	48	38	32	27	11	5				
SEP 1	170	100	153	112	88	65	35	29								
SEP 11	170	147	312	229	159	112	71	47	35	18	12	6				
SEP 21	170	124	265	159	106	59	35	24	12	6						
OCT 1	150	120	347	240	187	113	60	40	20	13						
OCT 11	130	100	346	238	169	108	85	46	38	15	8	8				
MONTH																
JUN	510	90	365	261	188	129	76	49	33	24	14	10	2			
JUL	527	99	173	106	78	49	32	17	9	8	6	2				
AUG	526	95	181	133	97	57	34	27	19	15	10	6				
SEP	510	124	243	167	118	78	47	33	16	8	4	2				

Table 7.—Precipitation: frequency distributions of daily amounts (inches)

PRECIPITATION - PERCENT FREQUENCY OF PERIOD TOTALS (INCHES)

- GIVEN TO NEAREST TENTH PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241507 NINEMILE RS 1956-1970

PERIOD BEGINS	NUM. YEARS	TR	≥ .01	≥ .05	≥ .10	≥ .20	≥ .30	≥ .40	≥ .50	≥ .60	≥ .80	≥1.00	≥1.50	≥2.00	≥3.00	≥4.00
MAY 11	16		875	813	813	688	563	500	438	438	188	188				
MAY 21	17		1000	941	941	882	705	588	529	294	235	118				
JUN 1	17		982	882	824	765	647	647	647	588	529	471	176	59		
JUN 11	17		1000	1000	1000	941	824	706	647	471	294	176	59			
JUN 21	17		941	941	765	588	588	529	529	471	118	118	59	59	59	59
JUL 1	17	59	882	824	647	529	529	529	471	353	118	118				
JUL 11	17	118	765	706	588	412	353	235	118	118	118	118	59			
JUL 21	17	118	647	529	529	294	235	59	59	59	59					
AUG 1	17	59	705	588	471	412	353	235	176	175	118	119				
AUG 11	17	176	588	471	412	353	176	176	176	118	59	59	59	59		
AUG 21	17		824	824	824	765	588	471	471	412	235	176	118			
SEP 1	17	59	647	588	529	529	529	471	235	176	59					
SEP 11	17		1000	982	982	765	647	412	412	353	294	235	118			
SEP 21	17	59	882	824	706	647	471	412	294	176	59	59				
OCT 1	15		1000	933	933	867	733	733	600	467	267					
OCT 11	13		846	846	846	769	692	615	538	385	385	231	77			
MONTH																
JUN	17		1000	1000	1000	1000	1000	1000	1000	882	882	882	765	588	59	59
JUL	17		1000	1000	824	765	647	588	588	529	529	353	235	118		
AUG	17	59	982	982	824	824	824	765	765	765	588	412	353	176	59	
SEP	17		1000	1000	1000	1000	1000	982	824	824	647	471	235	235	59	

Table 8.—Precipitation: frequency distributions of 10-day and monthly totals (inches)

D R Y   B U L B   T E M P E R A T U R E

MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241507   NINEMILE RS

1954-1970

PRD. BEGINS	10-DAY AND MONTHLY PERIOD MEANS: MEAN	STD. DEV.	MEDIAN	HIGHEST AVG.YR	LOWEST AVG.YR	10-DAY AND MONTHLY EXTREMES: HIGH.YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW.YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
MAY 11	63.0	5.1	62.0	72.3 54	55.7 66	86 58	76.3	5.9	76.0	41 59	48.1	5.1	49.0	MAY 11
MAY 21	65.4	7.3	65.0	81.4 58	53.6 55	90 66	75.8	7.8	78.0	41 60	52.9	8.7	51.0	MAY 21
JUN 1	68.3	5.8	66.0	77.4 70	60.8 54	90 57	79.8	6.2	82.0	48 65	56.9	6.5	55.0	JUN 1
JUN 11	70.0	5.1	69.0	82.4 61	62.2 64	94 61	84.1	6.0	84.0	44 69	56.0	6.9	55.0	JUN 11
JUN 21	72.3	6.2	71.0	82.5 61	60.1 69	96 55	84.9	5.8	85.0	50 69	58.2	7.3	55.0	JUN 21
JUL 1	78.3	6.0	79.0	88.1 69	64.2 55	95 68	89.6	4.5	91.0	55 55	64.9	6.8	62.0	JUL 1
JUL 11	82.7	5.4	81.0	94.6 60	73.3 63	102 60	92.1	4.1	92.0	56 70	70.2	9.3	70.0	JUL 11
JUL 21	84.4	3.8	85.0	90.8 60	74.9 70	99 60	92.2	3.8	91.0	57 54	71.8	7.4	74.0	JUL 21
AUG 1	82.7	4.5	84.0	90.2 61	73.9 62	102 61	92.1	3.8	92.0	58 56	69.1	7.2	68.0	AUG 1
AUG 11	82.3	6.6	83.0	94.6 67	65.4 68	98 67	91.4	3.7	91.0	53 68	69.3	10.7	68.0	AUG 11
AUG 21	76.5	7.3	74.0	87.5 67	65.8 60	99 69	89.1	6.3	90.0	53 64	63.1	8.6	62.0	AUG 21
SEP 1	74.2	7.3	73.0	87.3 55	62.2 65	97 67	85.9	6.1	85.0	42 62	59.3	8.9	58.0	SEP 1
SEP 11	67.5	7.7	68.0	78.7 56	48.3 65	91 59	81.1	8.3	85.0	36 65	52.0	8.3	53.0	SEP 11
SEP 21	65.3	8.5	63.0	78.7 67	53.7 59	90 67	76.3	8.0	76.0	42 68	51.5	8.3	49.0	SEP 21
OCT 1	59.1	6.0	59.0	67.5 56	50.2 59	79 63	71.5	6.8	73.0	38 70	47.3	6.4	46.0	OCT 1
OCT 11	54.4	4.6	54.0	64.1 63	47.8 68	76 64	64.3	6.5	62.0	35 61	44.8	4.5	46.0	OCT 11
MONTH														MONTH
JUN	70.2	3.2	69.0	79.6 61	67.1 66	96 55	88.2	3.6	87.0	44 69	52.1	3.9	52.0	JUN
JUL	81.9	3.4	81.0	90.3 60	77.5 55	102 60	94.4	3.2	94.0	55 55	62.5	6.2	61.0	JUL
AUG	80.4	5.0	80.0	89.6 67	73.9 68	102 61	94.5	3.3	94.0	53 68	61.1	7.3	62.0	AUG
SEP	69.3	6.2	69.0	79.5 67	56.5 65	97 67	86.7	5.5	88.0	36 65	46.7	6.2	44.0	SEP

R E L A T I V E   H U M I D I T Y

MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241507   NINEMILE RS

1954-1970

PRD. BEGINS	10-DAY AND MONTHLY PERIOD MEANS: MEAN	STD. DEV.	MEDIAN	HIGHEST AVG.YR	LOWEST AVG.YR	10-DAY AND MONTHLY EXTREMES: HIGH.YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW.YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
MAY 11	45.0	11.7	42.0	72.0 62	26.9 65	100 55	74.8	15.2	71.5	11 64	24.5	8.6	22.5	MAY 11
MAY 21	46.3	10.0	45.0	67.1 62	32.1 63	100 60	76.2	13.4	78.0	15 65	27.0	7.6	29.0	MAY 21
JUN 1	47.7	11.0	49.0	67.3 58	27.0 65	94 64	72.4	18.2	74.0	14 70	27.6	5.7	27.0	JUN 1
JUN 11	48.6	9.4	48.0	62.0 65	28.7 61	100 56	80.1	14.0	83.0	6 68	24.2	7.3	24.0	JUN 11
JUN 21	42.1	10.4	43.0	59.2 69	20.9 61	95 58	71.0	16.0	75.0	9 64	21.3	6.5	22.0	JUN 21
JUL 1	35.5	10.5	33.0	60.5 55	19.3 67	89 65	62.5	20.8	68.0	11 66	20.8	6.4	20.0	JUL 1
JUL 11	31.0	8.3	33.0	47.0 55	18.7 60	100 55	59.1	24.5	55.0	9 67	18.0	5.8	17.0	JUL 11
JUL 21	24.5	6.9	20.0	38.0 55	12.7 66	84 70	46.5	18.7	47.0	9 65	14.3	3.4	15.0	JUL 21
AUG 1	26.7	9.7	24.0	45.8 65	15.7 69	89 62	53.1	23.7	45.0	8 67	14.6	4.5	14.0	AUG 1
AUG 11	26.4	10.7	23.0	58.2 69	11.2 67	94 68	47.3	21.4	43.0	6 67	13.2	3.5	13.0	AUG 11
AUG 21	33.3	12.2	32.0	53.1 65	14.1 69	89 56	60.9	21.7	61.0	8 66	17.8	7.5	16.0	AUG 21
SEP 1	32.9	9.3	36.0	47.5 65	20.1 69	95 63	61.8	21.1	58.0	10 57	17.7	6.0	17.0	SEP 1
SEP 11	42.0	11.3	37.0	65.3 65	25.4 55	100 65	73.6	17.7	75.0	16 69	22.6	9.4	20.0	SEP 11
SEP 21	41.6	9.9	40.0	60.1 59	24.0 67	94 65	71.8	14.7	74.0	13 67	23.9	6.9	23.0	SEP 21
OCT 1	49.5	9.9	48.0	71.8 57	34.5 60	100 55	80.9	12.7	83.0	13 60	27.1	9.7	25.0	OCT 1
OCT 11	54.6	12.1	56.0	72.6 57	34.7 70	100 61	82.0	15.7	92.0	14 64	34.9	12.4	35.0	OCT 11
MONTH														MONTH
JUN	46.1	6.4	45.0	56.8 59	30.4 61	100 56	84.9	12.8	89.0	6 68	18.9	6.1	20.0	JUN
JUL	30.1	7.3	31.0	48.2 55	20.0 67	100 55	74.4	17.0	79.0	9 67	13.8	3.4	15.0	JUL
AUG	28.9	9.1	25.0	43.6 65	15.5 67	94 68	68.8	21.4	73.0	6 67	12.2	3.5	13.0	AUG
SEP	38.4	8.3	37.0	55.0 65	25.6 67	100 65	84.2	10.4	83.0	10 67	16.1	5.0	16.0	SEP

D E W   P O I N T

MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241507   NINEMILE RS

1954-1970

PRD. BEGINS	10-DAY AND MONTHLY PERIOD MEANS: MEAN	STD. DEV.	MEDIAN	HIGHEST AVG.YR	LOWEST AVG.YR	10-DAY AND MONTHLY EXTREMES: HIGH.YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW.YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
MAY 11	38.7	5.4	38.0	47.1 62	28.3 65	60 60	47.0	5.9	46.5	12 65	29.5	7.6	30.5	MAY 11
MAY 21	41.9	4.3	40.0	49.1 59	35.5 59	58 66	50.8	4.4	51.0	19 67	32.4	7.3	31.0	MAY 21
JUN 1	45.5	3.7	45.0	52.4 57	37.9 65	62 69	53.1	4.5	53.0	31 68	36.4	3.6	37.0	JUN 1
JUN 11	47.2	3.3	47.0	53.2 63	39.5 69	67 63	56.8	5.3	56.0	2 68	35.9	9.9	40.0	JUN 11
JUN 21	45.1	3.9	45.0	52.1 54	37.5 61	67 62	55.9	5.1	55.0	16 64	35.4	6.9	37.0	JUN 21
JUL 1	45.7	4.9	46.0	53.4 63	36.4 67	63 55	55.7	5.0	56.0	25 62	37.3	5.6	38.0	JUL 1
JUL 11	46.4	6.1	45.0	61.6 55	37.8 69	70 55	55.6	6.2	54.0	24 67	36.3	8.0	35.0	JUL 11
JUL 21	41.8	5.6	40.0	52.1 55	29.8 66	65 56	52.4	8.1	53.0	21 66	31.9	6.5	31.0	JUL 21
AUG 1	41.7	5.4	40.0	54.0 65	33.4 69	63 56	53.0	7.1	54.0	23 61	32.3	6.7	30.0	AUG 1
AUG 11	40.8	5.2	41.0	48.2 65	31.2 67	63 65	51.2	6.1	52.0	17 67	30.1	6.5	32.0	AUG 11
AUG 21	41.3	5.8	41.0	49.7 56	30.4 70	60 65	51.5	5.5	50.0	16 69	31.2	8.3	31.0	AUG 21
SEP 1	39.9	4.3	39.0	47.0 68	31.5 69	60 63	49.0	5.2	49.0	21 62	29.3	5.5	27.0	SEP 1
SEP 11	40.4	4.3	40.0	48.5 59	30.1 70	59 59	50.0	4.0	50.0	17 70	30.6	7.0	32.0	SEP 11
SEP 21	38.7	3.8	38.0	45.2 63	32.0 61	58 63	48.4	5.0	47.0	23 70	30.7	4.8	30.0	SEP 21
OCT 1	37.8	3.7	36.0	44.2 63	33.0 61	55 64	46.7	4.1	46.0	21 61	28.9	4.9	28.0	OCT 1
OCT 11	36.6	6.8	37.0	44.0 57	22.0 69	56 57	45.2	5.5	46.0	7 69	26.2	10.3	29.0	OCT 11
MONTH														MONTH
JUN	46.0	2.5	46.0	51.1 58	41.3 68	67 63	59.8	4.6	59.0	2 68	30.6	9.1	33.0	JUN
JUL	44.5	4.4	44.0	54.2 55	37.8 66	70 55	59.2	4.9	59.0	21 65	30.2	6.0	30.0	JUL
AUG	41.2	4.9	42.0	50.3 65	33.2 69	63 65	56.1	4.9	57.0	16 69	26.7	5.6	27.0	AUG
SEP	39.7	3.3	39.0	45.4 68	34.1 70	60 63	52.5	4.0	52.0	17 70	25.6	5.4	26.0	SEP

Table 9.—Dry bulb (°F), relative humidity (percent), and dewpoint (°F) at 1600 m.s.t. Note: Relative humidity listed for Williams Peak averages 1 percent too high, due to approximation in formula used to compute values

DRY BULB TEMPERATURE — MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241305 WILLIAMS PEAK 1954-1970

	10-DAY AND MONTHLY PERIOD MEANS					10-DAY AND MONTHLY EXTREMES								
PRD. BEGINS	MEAN	STD. DEV.	MEDIAN	HIGHEST AVG,YR	LOWEST AVG,YR	HIGH,YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW,YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
JUL 1	70.1	6.5	68.0	83.8 68	61.7 58	89 68	79.2	5.5	79.0	47 57	58.2	10.8	52.5	JUL 1
JUL 11	73.2	4.9	73.0	83.4 60	65.6 63	91 60	81.6	4.4	83.0	47 70	61.9	8.7	60.0	JUL 11
JUL 21	73.9	3.1	74.0	78.1 56	68.4 70	89 68	82.6	3.3	83.0	44 54	61.4	7.5	63.0	JUL 21
AUG 1	72.3	4.6	73.0	80.5 61	64.4 62	92 61	82.2	4.0	81.0	50 62	58.2	6.4	56.0	AUG 1
AUG 11	72.5	5.8	72.0	87.1 67	64.0 59	91 67	81.9	4.7	82.0	41 64	59.6	10.6	60.0	AUG 11
AUG 21	68.0	8.0	68.5	82.5 70	54.2 60	90 69	80.9	6.1	82.0	42 60	54.2	11.8	49.0	AUG 21
MONTH														MONTH
JUL	73.0	3.2	72.0	78.5 60	67.8 58	91 60	84.3	3.4	84.0	44 54	55.3	7.4	53.0	JUL
AUG	71.2	4.9	72.0	80.7 67	62.4 60	92 61	85.3	4.1	86.0	41 64	50.8	7.4	51.0	AUG

RELATIVE HUMIDITY — MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241305 WILLIAMS PEAK 1954-1970

	10-DAY AND MONTHLY PERIOD MEANS					10-DAY AND MONTHLY EXTREMES								
PRD. BEGINS	MEAN	STD. DEV.	MEDIAN	HIGHEST AVG,YR	LOWEST AVG,YR	HIGH,YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW,YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
JUL 1	40.0	8.9	36.5	53.2 58	30.0 60	88 56	60.4	18.0	59.5	14 57	25.9	7.5	25.5	JUL 1
JUL 11	38.9	7.0	40.0	53.8 64	23.6 60	100 64	63.9	22.3	62.0	17 60	25.1	4.7	26.0	JUL 11
JUL 21	36.0	7.4	34.0	48.6 70	22.1 66	89 65	59.4	17.6	56.0	16 66	22.5	3.5	23.0	JUL 21
AUG 1	38.1	9.1	38.0	57.6 62	25.6 59	100 65	68.5	23.0	68.0	17 69	23.6	4.7	24.0	AUG 1
AUG 11	37.1	9.5	37.0	52.7 64	21.4 70	94 59	60.7	19.4	62.0	15 70	22.2	5.5	21.0	AUG 11
AUG 21	41.7	13.7	42.0	59.8 60	16.6 70	94 56	69.4	26.1	83.0	9 70	23.6	9.9	24.0	AUG 21
MONTH														MONTH
JUL	38.0	6.5	40.0	49.5 64	26.5 66	100 64	74.1	17.4	68.0	14 57	20.4	3.4	21.0	JUL
AUG	39.2	8.8	38.0	53.6 60	25.1 67	100 65	82.1	18.0	89.0	9 70	19.4	6.0	20.0	AUG

Table 9.—(con.)

D R Y   B U L B   T E M P E R A T U R E

PERCENTAGE FREQUENCY DISTRIBUTION OF DAILY VALUES
-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241507   NINEMILE RS   1954-1970

PRD. BEGINS	BELOW 0	0 TO 4	5 TO 9	10 TO 14	15 TO 19	20 TO 24	25 TO 29	30 TO 34	35 TO 39	40 TO 44	45 TO 49	50 TO 54	55 TO 59	60 TO 64	65 TO 69	70 TO 74	75 TO 79	80 TO 84	85 TO 89	90 TO 94	95 TO 99	100 AND ABOVE	PRD. BEGINS
MAY 11										34	74	155	135	128	162	149	95	54	14				MAY 11
MAY 21										13	31	94	182	145	145	132	151	94	5	6			MAY 21
JUN 1											6	71	147	124	188	224	124	65	47	6			JUN 1
JUN 11										6	12	53	118	159	141	129	159	135	59	29			JUN 11
JUN 21												59	94	124	129	141	135	188	100	24	6		JUN 21
JUL 1													53	65	88	153	112	176	229	118	6		JUL 1
JUL 11													6	35	24	112	141	218	229	176	53	6	JUL 11
JUL 21													11	5	32	53	86	241	348	187	37		JUL 21
AUG 1													6	35	53	65	112	224	288	182	29	6	AUG 1
AUG 11												12	35	18	59	41	124	182	312	171	47		AUG 11
AUG 21												20	66	77	107	128	158	163	148	92	41		AUG 21
SEP 1										6		50	44	139	117	133	128	156	144	72	11		SEP 1
SEP 11									6	40	17	69	145	127	92	145	145	145	64	6			SEP 11
SEP 21										37	93	93	99	142	123	136	136	117	19	6			SEP 21
OCT 1									8	92	123	154	162	138	123	100	100						OCT 1
OCT 11									9	85	222	256	197	85	85	51	9						OCT 11
MONTH																							MONTH
JUN										2	6	61	120	135	153	165	139	129	69	20	2		JUN
JUL													23	34	47	104	112	213	271	161	32	2	JUL
AUG												11	37	45	75	90	132	188	244	146	39	2	AUG
SEP									2	27	35	70	95	136	111	138	136	140	79	29	4		SEP

R E L A T I V E   H U M I D I T Y

PERCENTAGE FREQUENCY DISTRIBUTION OF DAILY VALUES
-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241507   NINEMILE RS   1954-1970

PRD. BEGINS	BELOW 0	0 TO 4	5 TO 9	10 TO 14	15 TO 19	20 TO 24	25 TO 29	30 TO 34	35 TO 39	40 TO 44	45 TO 49	50 TO 54	55 TO 59	60 TO 64	65 TO 69	70 TO 74	75 TO 79	80 TO 84	85 TO 89	90 TO 94	95 TO 99	100 AND ABOVE	PRD. BEGINS
MAY 11				14	14	35	182	108	68	108	68	61	61	27	68	34	14	7	34	34		7	MAY 11
MAY 21					44	53	75	164	113	126	57	57	57	57	38	38	50	38	13	6		5	MAY 21
JUN 1				6		53	124	129	94	76	100	88	71	65	53	53	12	35	24	18			JUN 1
JUN 11			6	6	12	55	65	176	71	65	82	88	76	59	53	53	53	24	18	12		18	JUN 11
JUN 21			6	6	71	100	135	141	53	100	94	65	35	24	59	24	47	12	24		6		JUN 21
JUL 1				24	129	200	135	112	100	59	59	29	41	6	29		41	29	6				JUL 1
JUL 11			6	29	153	235	153	135	88	71	35	24	12	12	6	6	12	6	12			6	JUL 11
JUL 21			11	107	321	209	112	96	43	32	16	11	27		5	5		5					JUL 21
AUG 1			12	135	229	235	82	112	82	12	18	18		6	12	18	6	12	12				AUG 1
AUG 11			29	147	247	147	135	118	47	29	29	12		12	12	12			18	6			AUG 11
AUG 21			26	92	184	117	97	97	56	82	46	56	31	46	20	10	10	15	15				AUG 21
SEP 1				56	200	150	139	128	72	56	50	50	22	17	11	11	11	17		6	6		SEP 1
SEP 11					75	121	179	156	69	29	92	46	40	40	29	35	29	23	12	12		12	SEP 11
SEP 21				6	43	160	93	142	86	123	68	25	80	37	49	6	6	31	37	6			SEP 21
OCT 1				8	31	46	69	100	108	100	100	77	69	38	54	31	54	23	46	38		8	OCT 1
OCT 11				9	17	17	43	60	137	94	103	60	68	85	94	51	26	17	60	51		9	OCT 11
MONTH																							MONTH
JUN			4	6	27	73	108	149	73	80	92	80	61	49	55	43	37	24	22	10	2	6	JUN
JUL			5	55	205	214	133	114	76	53	35	21	27	6	13	4	17	13	5			2	JUL
AUG			22	123	218	164	104	108	62	43	32	30	11	22	15	13	6	9	15	2			AUG
SEP				21	109	144	138	142	76	68	70	41	47	31	29	17	16	23	15	8	2	4	SEP

Table 10.—Dry bulb temperature (°F) and relative humidity (percent): frequency distributions

MAXIMUM TEMPERATURE — MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241507 NINEMILE RS — 1954-1970

PRD. BEGINS	MEAN	STD. DEV.	MEDIAN	HIGHEST AVG,YR	LOWEST AVG,YR	HIGH,YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW,YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
	10-DAY AND MONTHLY PERIOD MEANS					10-DAY AND MONTHLY EXTREMES								
MAY 11	68.1	5.3	66.0	77.0 64	57.8 66	95 55	80.5	7.4	79.5	45 58	54.8	6.2	55.0	MAY 11
MAY 21	70.7	7.0	69.0	85.4 59	61.3 55	90 66	81.1	6.3	82.0	46 57	58.5	8.6	58.0	MAY 21
JUN 1	74.1	5.3	72.0	82.2 70	67.8 66	94 57	83.1	6.1	84.0	52 66	63.4	6.5	61.0	JUN 1
JUN 11	75.5	6.0	74.0	88.4 61	67.4 70	102 65	87.5	6.3	86.0	54 56	62.3	6.5	61.0	JUN 11
JUN 21	78.6	6.5	81.0	87.8 61	63.4 69	98 55	87.9	5.8	88.0	53 69	64.7	7.2	62.0	JUN 21
JUL 1	83.9	5.7	85.0	89.8 69	69.6 55	97 63	92.4	4.1	94.0	60 55	73.3	6.8	73.0	JUL 1
JUL 11	88.0	5.4	88.0	99.4 60	78.5 63	105 60	95.5	4.4	95.0	53 63	78.6	7.5	77.0	JUL 11
JUL 21	89.5	3.7	88.0	96.6 60	82.3 70	103 60	95.5	3.4	94.0	74 70	81.4	5.0	82.0	JUL 21
AUG 1	98.9	4.0	88.0	97.8 61	81.6 62	106 61	96.1	4.0	96.0	66 64	78.5	6.4	80.0	AUG 1
AUG 11	87.9	6.0	88.0	99.9 67	71.3 68	102 67	94.8	4.1	94.0	58 68	78.8	9.7	80.0	AUG 11
AUG 21	82.3	6.8	80.0	94.1 67	73.4 60	102 66	92.8	6.1	94.0	52 65	71.6	8.4	71.0	AUG 21
SEP 1	79.6	7.4	79.0	93.3 55	69.1 64	102 67	88.9	6.5	89.0	54 65	67.1	8.5	65.0	SEP 1
SEP 11	73.7	7.9	75.0	84.3 55	54.0 65	95 59	85.1	8.6	87.0	42 55	60.8	11.2	60.0	SEP 11
SEP 21	70.5	9.1	59.0	88.4 67	58.2 61	94 67	79.2	8.7	79.0	44 61	57.7	10.5	54.0	SEP 21
OCT 1	64.5	6.3	54.0	73.5 60	53.9 69	92 57	76.3	8.6	77.0	40 70	52.1	7.5	50.0	OCT 1
OCT 11	59.5	6.0	50.0	68.2 63	49.3 69	77 64	67.9	7.3	70.0	41 69	49.2	4.3	49.0	OCT 11
MONTH														MONTH
JUN	76.1	3.2	76.0	86.1 61	71.5 65	102 65	92.1	4.2	91.0	52 65	58.8	5.2	58.0	JUN
JUL	87.2	3.5	86.0	95.1 60	82.4 69	105 60	97.2	3.5	97.0	60 55	71.8	6.8	73.0	JUL
AUG	86.3	4.6	85.5	95.7 67	77.9 68	106 61	97.9	3.2	97.0	58 68	70.6	7.9	71.0	AUG
SEP	74.8	6.5	75.0	87.5 67	62.3 65	102 67	89.7	6.2	90.0	42 55	54.2	9.0	52.0	SEP

MINIMUM TEMPERATURE — MEAN, STANDARD DEVIATION, AND EXTREME VALUES

STATION NUMBER 241507 NINEMILE RS — 1954-1970

PRD. BEGINS	MEAN	STD. DEV.	MEDIAN	HIGHEST AVG,YR	LOWEST AVG,YR	HIGH,YR	AVG. HIGH	STD. DEV.	MEDIAN HIGH	LOW,YR	AVG. LOW	STD. DEV.	MEDIAN LOW	PRD. BEGINS
	10-DAY AND MONTHLY PERIOD MEANS					10-DAY AND MONTHLY EXTREMES								
MAY 11	34.7	3.2	34.0	40.4 57	28.3 66	57 62	43.4	5.6	43.0	20 66	26.6	3.5	27.0	MAY 11
MAY 21	36.8	3.2	36.0	46.8 58	33.8 59	53 55	44.7	3.9	43.0	22 66	28.9	4.9	28.0	MAY 21
JUN 1	40.2	3.7	41.0	45.7 57	32.4 62	52 68	47.0	4.4	47.0	27 62	33.8	3.3	34.0	JUN 1
JUN 11	41.7	2.2	41.0	47.0 58	38.0 69	62 54	49.6	4.1	49.0	28 54	33.8	3.6	34.0	JUN 11
JUN 21	40.8	3.4	40.0	49.1 70	36.0 56	60 70	50.4	5.8	48.0	27 64	32.6	3.1	33.0	JUN 21
JUL 1	43.4	2.9	43.0	50.3 64	38.9 59	69 64	52.9	5.8	52.0	29 62	35.4	2.7	35.0	JUL 1
JUL 11	45.6	2.8	45.0	51.1 55	40.9 63	66 62	54.9	5.0	54.0	31 62	38.5	4.4	39.0	JUL 11
JUL 21	43.8	3.4	43.0	49.3 55	36.3 63	67 62	54.1	6.4	55.0	31 59	36.4	3.6	36.0	JUL 21
AUG 1	43.3	2.1	42.5	47.4 60	39.7 69	59 70	52.0	4.0	50.5	32 69	36.4	2.8	36.0	AUG 1
AUG 11	42.4	2.8	41.0	46.9 69	37.1 64	59 65	51.3	5.4	51.0	31 54	35.3	2.4	36.0	AUG 11
AUG 21	41.6	3.6	41.0	48.2 65	35.8 52	65 65	51.5	6.9	51.0	26 65	32.6	3.5	32.0	AUG 21
SEP 1	38.1	4.1	38.0	45.6 63	28.8 62	59 67	48.3	6.0	49.0	21 62	28.9	4.4	28.0	SEP 1
SEP 11	36.6	5.2	36.0	46.0 59	27.3 64	55 59	46.8	5.0	47.0	16 70	27.5	7.0	28.0	SEP 11
SEP 21	34.3	3.7	34.0	40.2 69	27.8 70	48 63	43.5	2.5	43.0	18 64	26.4	4.6	27.0	SEP 21
OCT 1	31.4	3.5	30.0	37.8 63	22.7 64	50 62	41.1	5.2	40.0	15 64	24.6	3.8	24.0	OCT 1
OCT 11	29.5	4.4	30.0	35.4 59	19.9 59	48 59	40.2	4.9	40.0	15 69	21.2	4.0	22.0	OCT 11
MONTH														MONTH
JUN	40.9	2.3	40.0	45.3 58	37.2 62	62 54	53.0	5.0	52.0	27 64	30.8	2.3	31.0	JUN
JUL	44.2	1.9	43.0	47.4 55	40.8 63	69 64	57.9	5.0	57.0	29 62	33.9	2.0	34.0	JUL
AUG	42.5	2.3	42.0	46.8 65	38.3 64	65 65	55.8	4.4	56.0	26 65	32.1	2.9	31.5	AUG
SEP	36.4	3.4	36.0	41.9 59	29.9 64	59 67	49.9	4.9	51.0	16 70	24.6	4.1	26.0	SEP

Table 11.—Daily maximum and minimum temperatures (°F): mean, median, and extreme (based on 24 hours ending at 1600 m.s.t.)

M A X I M U M   T E M P E R A T U R E

PERCENTAGE FREQUENCY DISTRIBUTION OF DAILY VALUES
-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241507   NINEMILE RS   1954-1970

PRD. BEGINS	BELOW 0	0 TO 4	5 TO 9	10 TO 14	15 TO 19	20 TO 24	25 TO 29	30 TO 34	35 TO 39	40 TO 44	45 TO 49	50 TO 54	55 TO 59	60 TO 64	65 TO 69	70 TO 74	75 TO 79	80 TO 84	85 TO 89	90 TO 94	95 TO 99	100 AND ABOVE	PRD. BEGINS
MAY 11											32	90	97	148	174	200	129	65	52		13		MAY 11
MAY 21											23	11	80	189	154	143	189	131	57	23			MAY 21
JUN 1												6	35	88	153	241	200	153	88	35			JUN 1
JUN 11												6	47	118	142	112	207	172	124	47	18	6	JUN 11
JUN 21												12	24	82	100	112	153	188	188	118	24		JUN 21
JUL 1														29	35	100	118	176	253	224	65		JUL 1
JUL 11														6		47	100	153	235	265	147	47	JUL 11
JUL 21																27	27	124	269	382	140	32	JUL 21
AUG 1															12	18	65	135	247	371	118	35	AUG 1
AUG 11													12	12	18	29	35	124	282	324	124	41	AUG 11
AUG 21														41	72	108	169	159	190	123	123	15	AUG 21
SEP 1												11	11	67	83	133	161	172	172	128	50	11	SEP 1
SEP 11										17	6	23	85	113	96	124	141	203	147	40	6		SEP 11
SEP 21										6	12	106	71	135	147	124	147	112	82	59			SEP 21
OCT 1										29	80	101	101	210	159	101	145	58	7	7			OCT 1
OCT 11										40	97	202	218	129	153	129	32						OCT 11
MONTH																							MONTH
JUN												8	35	96	132	155	187	171	134	67	14	2	JUN
JUL														11	11	57	80	150	253	293	118	27	JUL
AUG													4	19	36	54	93	140	237	265	121	30	AUG
SEP										8	6	46	55	104	109	127	150	163	135	76	19	4	SEP

M I N I M U M   T E M P E R A T U R E

PERCENTAGE FREQUENCY DISTRIBUTION OF DAILY VALUES
-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241507   NINEMILE RS   1954-1970

PRD. BEGINS	BELOW 0	0 TO 4	5 TO 9	10 TO 14	15 TO 19	20 TO 24	25 TO 29	30 TO 34	35 TO 39	40 TO 44	45 TO 49	50 TO 54	55 TO 59	60 TO 64	65 TO 69	70 TO 74	75 TO 79	80 TO 84	85 TO 89	90 TO 94	95 TO 99	100 AND ABOVE	PRD. BEGINS
MAY 11						49	140	343	245	154	56		14										MAY 11
MAY 21						27	93	273	240	273	67	27											MAY 21
JUN 1							13	161	302	275	174	74											JUN 1
JUN 11							7	110	241	317	269	48		7									JUN 11
JUN 21							27	141	227	351	169	52	13	19									JUN 21
JUL 1							6	37	239	325	258	98	18	12	6								JUL 1
JUL 11								24	136	254	367	160	36	18	6								JUL 11
JUL 21								43	243	330	200	97	70	11	5								JUL 21
AUG 1								31	231	375	244	75	44										AUG 1
AUG 11								71	276	335	206	65	47										AUG 11
AUG 21							16	135	238	285	192	98	16	10	10								AUG 21
SEP 1						18	119	205	239	216	114	85	6										SEP 1
SEP 11					18	49	132	246	180	204	108	60	6										SEP 11
SEP 21					20	39	171	257	289	151	72												SEP 21
OCT 1					8	152	256	304	160	64	48	8											OCT 1
OCT 11					103	130	224	250	121	95	17												OCT 11
MONTH																							MONTH
JUN							18	136	257	315	203	58	4	9									JUN
JUL							2	35	207	304	273	118	43	14	6								JUL
AUG							6	82	249	329	212	80	34	4	4								AUG
SEP					12	34	139	234	234	192	99	50	4										SEP

Table 12.—Daily maximum and minimum temperatures (°F): frequency distributions (based on 24 hours ending at 1600 m.s.t.)

WIND SPEED - DIRECTION

PERCENTAGE FREQUENCY OF OCCURRENCE BY DIRECTION FOR SELECTED SPEED INCREMENTS

-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241510 WEST FORK BUTTE 1953-1963

MONTH JUL

DIR.	0-3 N.	0-3 PCT	4-7 N.	4-7 PCT	8-12 N.	8-12 PCT	13-18 N.	13-18 PCT	19-24 N.	19-24 PCT	≥25 N.	≥25 PCT	TOTAL N.	TOTAL PCT	AVG SPEED
NE	1	4	11	43	1	4							13	51	5.23
E	4	16	7	28	6	23	1	4					18	71	6.56
SE			2	8	2	8							4	16	7.50
S					3	12	1	4					4	16	10.25
SW			9	35	18	71	13	51	4	16			44	173	11.39
W	1	4	21	83	68	268	44	173	11	43	2	8	147	579	12.04
NW	2	8	5	20	6	23	5	20	1	4			19	74	9.16
N	2	8			1	4							3	12	4.67
CLM	2	8											2	8	0.00
TOT	12	47	55	217	105	413	64	252	16	63	2	8	254		10.69

MONTH AUG

DIR.	0-3 N.	0-3 PCT	4-7 N.	4-7 PCT	8-12 N.	8-12 PCT	13-18 N.	13-18 PCT	19-24 N.	19-24 PCT	≥25 N.	≥25 PCT	TOTAL N.	TOTAL PCT	AVG SPEED
NE	1	4	2	7	2	7							5	18	6.20
E	1	4	9	33	7	25							17	62	7.06
SE			6	22	3	11	2	7					11	40	8.91
S					1	4	2	7	1	4			4	14	14.75
SW			2	7	18	65	14	51	2	7			35	130	12.25
W	7	25	31	112	75	272	53	192	5	18	2	7	173	627	10.90
NW	2	7	8	29	9	32	3	11					22	80	8.27
N	1	4	2	7									3	11	3.33
CLM	5	18											5	18	0.00
TOT	17	62	60	217	115	417	74	268	8	29	2	7	276		10.30

STATION NUMBER 241305 WILLIAMS PEAK 1954-1970

MONTH JUL

DIR.	0-3 N.	0-3 PCT	4-7 N.	4-7 PCT	8-12 N.	8-12 PCT	13-18 N.	13-18 PCT	19-24 N.	19-24 PCT	≥25 N.	≥25 PCT	TOTAL N.	TOTAL PCT	AVG SPEED
NE	5	13	2	5			1	3					8	20	4.13
E	2	5	2	5			1	3					5	13	6.40
SE	4	10	4	10	1	3							9	23	4.33
S	8	20	36	91	33	84	15	38	4	10			96	244	8.92
SW	20	51	46	117	50	127	14	36	1	3			131	333	7.70
W	14	36	35	89	20	51	2	5					71	181	6.13
NW	5	13	23	59	14	36	1	3	1	3			44	112	6.57
N	6	15	3	8	2	5							11	28	4.18
CLM	18	46											18	46	0.00
TOT	82	209	151	384	120	305	34	87	6	15			393		6.97

MONTH AUG

DIR.	0-3 N.	0-3 PCT	4-7 N.	4-7 PCT	8-12 N.	8-12 PCT	13-18 N.	13-18 PCT	19-24 N.	19-24 PCT	≥25 N.	≥25 PCT	TOTAL N.	TOTAL PCT	AVG SPEED
NE	9	20	8	17	2	4							19	41	3.95
E	6	13	3	7									[illegible]	20	3.67
SE	1	2	3	7	3	7	1	2					8	17	7.38
S	13	28	34	74	35	76	16	35					98	214	8.22
SW	19	41	46	100	56	122	12	25	2	[illegible]			135	295	7.87
W	14	31	41	90	35	76	14	31	4	9			108	236	8.13
NW	6	13	10	22	6	13	9	20	1	2			32	70	8.75
N	3	7	3	7	1	2	1	2					9	17	6.13
CLM	41	90											41	90	0.00
TOT	112	245	148	323	138	301	53	115	7	15			458		7.08

Table 13.—Windspeed (mi/h) at 1600 m.s.t.: average and frequency distribution by direction

T E M P E R A T U R E - R E L A T I V E H U M I D I T Y - W I N D S P E E D
PERCENTAGE FREQUENCY OF OCCURRENCE FOR SELECTED COMBINATIONS
-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241507 NINEMILE RS 1954-1970

MONTH JUL

WIND SPEED 0-4 MPH — RELATIVE HUMIDITY

TEMP. DEG F	1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
≥100										
95-99		8		2						
90-94	2	21	19	13						
85-89		32	40	11		2				
80-84		9	38	21	5	4				
75-79			8	11	4	2	2			
70-74				9	5	9	2	2		
65-69					4	2		4	2	
60-64					2	2	4	4		2
55-59						2	2	4	4	
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL	2	70	104	68	21	23	9	13	6	2
NUMBER	1	37	55	36	11	12	5	7	3	1

WIND SPEED 5-9 MPH — RELATIVE HUMIDITY

TEMP. DEG F	1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
≥100										
95-99		13	4							
90-94		42	23	2						
85-89	2	27	53	15	4					
80-84	2	19	40	21	4	2				
75-79		2	19	11	11	2				
70-74			9	15	13	2	2	2		
65-69			2	8	2	6	4	2		
60-64					4	4		6	4	
55-59									2	
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL	4	102	150	72	38	15	6	9	6	
NUMBER	2	54	79	38	20	8	3	5	3	0

WIND SPEED 10-14 MPH — RELATIVE HUMIDITY

TEMP. DEG F	1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
≥100		2								
95-99	2	2	2							
90-94		25	4	2						
85-89	2	46	13	4	2					
80-84	2	15	17	6	2	2				
75-79		2	13	6	9	2				
70-74		4	5	8	8	4				
65-69		2		9	2					
60-64						2		2		
55-59					2		2		4	
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL	6	97	55	34	25	9	2	2	4	
NUMBER	3	51	29	18	13	5	1	1	2	0

WIND SPEED 15-19 MPH

TEMP. DEG F	1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
≥100										
95-99										
90-94		6								
85-89		13	6							
80-84		4								
75-79		4	2							
70-74				2	2					
65-69										
60-64										
55-59						2				
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL		27	8	2	2	2				
NUMBER	0	14	4	1	1	1	0	0	0	0

WIND SPEED GREATER/EQUAL 20 MPH

TEMP. DEG F	1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
≥100										
95-99										
90-94		4								
85-89										
80-84										
75-79		2								
70-74										
65-69										
60-64										
55-59										
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL		6								
NUMBER	0	3	0	0	0	0	0	0	0	0

TEMP. DEG F	TOTAL	NUMBER
≥100	2	1
95-99	32	17
90-94	161	85
85-89	271	143
80-84	213	112
75-79	112	59
70-74	104	55
65-69	47	25
60-64	34	18
55-59	23	12
50-54		0
45-49		0
40-44		0
35-39		0
30-34		0
<30		0
TOTAL	1000	
NUMBER		527

Table 14.—Dry bulb temperature (°F), relative humidity (percent), and windspeed (mi/h) combinations at 1600 m.s.t.: frequency distributions

TEMPERATURE - RELATIVE HUMIDITY - WINDSPEED
PERCENTAGE FREQUENCY OF OCCURRENCE FOR SELECTED COMBINATIONS
-GIVEN TO TENTHS PERCENT, DECIMAL POINT OMITTED

STATION NUMBER 241510 WEST FORK BUTTE 1953-1963

MONTH JUL

WIND SPEED 0-4 MPH

TEMP. DEG F	RH 1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
>100										
95-99										
90-94										
85-89										
80-84			4	12		4				
75-79			23	8						
70-74				12	8					
65-69			8	4	4		4			
60-64						4		4		
55-59									4	
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL			35	35	12	8	4	4	4	
NUMBER	0	0	9	9	3	2	1	1	1	0

WIND SPEED 5-9 MPH

TEMP. DEG F	RH 1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
>100										
95-99										
90-94			4							
85-89		16	4	12						
80-84	4	20	16	20						
75-79		12	39	16	4					
70-74			16	35	35	8	4			
65-69				20	16	4	4			
60-64					12	12	4	4		4
55-59				4				4		
50-54			4					4		
45-49										4
40-44										
35-39										
30-34										
<30										
TOTAL	4	47	82	105	66	23	12	12		8
NUMBER	1	12	21	27	17	6	3	3	0	2

WIND SPEED 10-14 MPH

TEMP. DEG F	RH 1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
>100										
95-99										
90-94			4							
85-89										
80-84			31	12						
75-79		20	39	27	12					
70-74		8	16	27	12	8				
65-69			8	8	12	4				
60-64			4	4	12	12	8	4		
55-59					8	8	4	4		
50-54									4	4
45-49									8	
40-44										
35-39										
30-34										
<30										
TOTAL		27	102	78	55	31	12	8	12	4
NUMBER	0	7	26	20	14	8	3	2	3	1

WIND SPEED 15-19 MPH

TEMP. DEG F	RH 1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
>100										
95-99										
90-94										
85-89										
80-84			12							
75-79			51	16	8					
70-74		4	16	23						
65-69				8	4					
60-64					8	4				
55-59				4	4	4	4			
50-54										
45-49										
40-44										
35-39										
30-34										
<30										
TOTAL		4	78	51	23	8	4			
NUMBER	0	1	20	13	5	2	1	0	0	0

WIND SPEED GREATER/EQUAL 20 MPH

TEMP. DEG F	RH 1 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 TO 100
>100										
95-99										
90-94										
85-89										
80-84										
75-79		4								
70-74		4	12							
65-69				4						
60-64				4		8				
55-59										
50-54										
45-49							4			
40-44										
35-39										4
30-34										
<30										
TOTAL		8	12	8		8	4			4
NUMBER	0	2	3	2	0	2	1	0	0	1

TEMP. DEG F	TOTAL	NUMBER
>100		0
95-99		0
90-94	8	2
85-89	31	8
80-84	133	34
75-79	277	71
70-74	246	63
65-69	109	28
60-64	109	28
55-59	51	13
50-54	16	4
45-49	15	4
40-44		0
35-39	4	1
30-34		0
<30		0
TOTAL	1000	
NUMBER		256

Table 14.—(con.)

Finklin, Arnold I. Summarizing weather and climatic data—a guide for wildland managers. Gen. Tech. Rep. INT-148. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 43 p.

Presents and illustrates methods the wildland manager can use to summarize available fire-weather and climatic data. The data analysis is in the form of frequency distributions as well as average values; these can be obtained largely through available computer programs. The scope also provides for general needs of forestry research.

KEYWORDS: climate, fire-weather, climatic data analysis, fire-management planning

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-149

July 1983

Proceedings— Range Economics Symposium and Workshop

August 31-September 2, 1982
Salt Lake City, Utah

FOREWORD

This symposium and workshop was designed to provide an opportunity for researchers and others directly involved in range economics to meet formally. Such a formal meeting had not taken place since the late 1960's at conferences sponsored by the Western Agricultural Economics Research Council (WAERC). Through the papers presented, discussions, and work sessions, a feeling for the state-of-the-art was gained. The amount of effort expended in range economic studies is at the lowest level in years and the immediate outlook for increased funding is not bright. There are, however, major problem areas that need immediate attention and considerable amounts of research effort.

Several papers were presented that are not included in these proceedings. These presentations were of a non-techical nature and the presentors did not submit documents for inclusion.

Of major interest is the consensus that a regional research coordinating committee would be desirable and that a followup meeting should be held in 1984 in connection with the Western Farm Economic Association annual meeting.

--Fred J. Wagstaff, Program Chairman

CONTENTS

Page

AN HISTORIC LOOK AT RANGE ECONOMICS RESEARCH

James R. Gray

ABSTRACT: Historic eras were designated frontier, descriptive, renaissance and public policy. Highly-trained economists appeared in the third era. After withdrawal of institutional support at the end of this era, the need for new normative research efforts generated the present momentum. Several successes and failures were noted.

INTRODUCTION

A coherent description of the historical aspects of range economics research requires some type of organization. The organization should have goals of identifying and categorizing like and unlike items by time periods. Consequently, the period being examined of about 110 years has been divided into four eras. Each period will be described in terms of the kinds of problems selected for range economics research, including a sample of those involved in the research, and a summary of the institutional units involved, kinds of publications, and economic tools most often used.

Inevitably, important individual and even group research contributions will be overlooked, partly because compilation of any history normally requires a period of years of search and analysis rather than the few weeks available to prepare this paper. Also, some bias will be apparent in the selection of topics because all of the speakers in this Range Economics Symposium have been actively involved in range economics research for periods up to and including three of the four eras to be described. Each has specialty areas. In any event, the guiding policy will be to attempt to avoid citing all of the literature dealing with particular problems and select only those considered as classics or turning points in the history of range economics research.

Major sources used in the organization and preparation of this paper were a book chapter[1] that failed to survive the editor's knife, and several bibliographies. Important bibliographies that should be in the libraries of historians are those by Renner (1938) dealing with the frontier period, an inventory of research followed by a supplement on economic development of western range resources by Cummings (1952; 1953), a selected bibliography on range resources and management by Caton (1954), and a range and ranch economics bibliography dealing with economic research in the use and development of range resources (Gray and El Saadi 1969).

THE FRONTIER PERIOD

Range economics research, including research dealing with the economics of the ranch firm, began about 1870. This beginning coincided with large-scale livestock migrations into the western range area from the east and south. As such, the economics research effort was as early, if not earlier, than research efforts of the other sciences having a western agricultural locale. Indeed, the one biological science most closely associated with range economics -- range management -- did not appear until after the beginning of the new century.

Land Utilization, Settlement and Public Land Administration

The earliest research efforts were concerned first with land utilization, settlement and public land administration. A second group was cost of production and the economics of ranching. The third group of problems was that involving marketing. Although a considerable number of articles were prepared both on national forest administration and range livestock associations during the frontier period, most of them were in popular trade journals or magazines. Many of these early articles were based more on casual observation and opinion rather than on systematic research procedures. The economic model used almost exclusively was the positive model and the descriptive results were prepared for non-professional audiences.

Some examples of the earliest research in land utilization, settlement, and public land administration were those of Powell (1879) in Utah and Donaldson's (1884) history of the public domain. Homesteading became a subject for considerable research, both economic and political (Sanborn 1900). Organization and operation of the Forest Service occurred at about this time and caused a considerable outpouring of articles, regulations and comment. Among the earliest were articles by Hermann (1902) and Roth (1902), a series of articles in the proceedings of the American Foresters' Congress by people such as

James R. Gray is Professor of Agricultural Economics and Agricultural Business, New Mexico State University, Las Cruces, N. Mex.

[1] Gray, James R. Las Cruces, N. Mex.: Research in range and ranch economics; chapter II manuscript; pp. 36-77, 1964.

Potter (1905), and the first of the grazing regulations by Pinchot (1908).

The growing controversy between range users and the federal land agencies regarding land utilization received much attention from authors such as Barnes (1916) and Authier (1925), with titles such as "Both Sides in the Range Controversy." The controversy evolved to the nub -- which group, ranchers or government, were to have final control of grazing.

Costs of Production and Economics of Ranching

Among the first of the studies of the costs of producing range livestock were those by Smith (1910) in Nebraska and Morton (1914) in Colorado. A large number of these studies were released over the next decade, involving almost all of the then active researchers in range economics. Examples in the two Great Basin states were Brennan and Smith (1928) in Nevada and Esplin and others (1928) in Utah. A list of those working in the various areas (without references to their works) would include Vass of Wyoming, Potter and Jardine of Oregon, Cox and Parr of Texas, Voorhies of California, Barber of Idaho, Pickrell of Arizona, Wilcox of Kansas, Hedges of Nebraska, Walker of New Mexico, and Klemmedson and Parr and Burdick of Colorado. All of these studies were published within a five-year period, 1925-1930. For those of us with over 20 years of experience in the field, these names are almost legendary in range economics research.

Two studies deserving special mention because they were the first of their kind were two region-wide studies. The comprehensive studies dealt with ranch organization and methods of livestock production in the Northern Plains (Wilson and others 1928) and in the Southwest (Parr and others 1928).

A unique comprehensive study was made by Bray (1928) and released by the Colorado station. Bray's study was entitled "Financing the Western Cattleman." Bray cited 113 pieces of literature on the subject of financing, including a book published by Larmer (1926).

Livestock Marketing

Livestock marketing was one of the first concerns of range economics researchers in the western range area because of the isolation of the area and distances to market. Subjects studied included product standards for wool (Bond 1873), sheep (Coffey 1908), horses (Davenport 1901), and cattle (Mumford 1902). Among the miscellaneous marketing subjects studied prior to 1920 were costs and methods of transporting products, cooperative marketing, accounting systems, exports and imports, shrinkage and prices. After 1920, subjects included carcass market classes and grades (by several authors), marketing costs, and association and cooperative marketing.

Other Characteristics

Almost all of the researchers of this period were untrained in the economics discipline. Rather, those educated prior to 1900 typically had bachelo of arts or science degrees which may or may not have been in agriculture. Those after 1900 were trained in agriculture, with specializations mainly in agronomy and animal husbandry. The organizations sponsoring research during the perio were mainly departments of agronomy and animal husbandry at the land grant colleges and the feder Department of Agriculture. The standard publication style was station bulletins, or farmer, technical or departmental bulletins of the federal establishment. Geographically, the various author conducted their research near their home bases, or at the most not farther than their state boundaries, with the exceptions noted above. A significant development in analysis occurred in the closing years of the period, when authors began to analyze ranch operations to isolate factors associated with profitability. If used at all, statistical analyses beyond measures of central tendency were limited to correlation analysis. Researchers of this period soon determined that ranches were too heterogeneous to permit much confidence in results of more sophisticated statistical analyses.

THE DESCRIPTIVE PERIOD, 1930-1949

In the descriptive period research efforts seemed to indicate a concern for the history of the industry as well as the necessity of inventorying and classifying rangeland resources. Taxation and finance became important subjects, particularly during the Great Depression, as well as tenure and appraisal situations and procedures. Probably from the earlier studies, the first of the analytical research efforts dealing with management appeared during the early portions of the period. It could be theorized that, with the exception of the inventory studies appearing in the mid and late 1930's, much of the research of the 1930's and early 1940's was based on research problems and methods introduced in the late 1920's. Few marketing studies were published prior to 1946. Also, organization and cost of production studies were numerous in some states as researchers, realizing that earlier efforts covered areas that were too broad, attempted numerous studies of much smaller areas.

A noteworthy accomplishment of this period was the appearance of the first general textbooks dealing mainly with the western livestock industry.

History of Western Ranching

Tremendous changes were taking place in the range livestock industry with the closing of the public

domain in 1934, along with widespread drought, unprecedented depression, mobilization for a second world war, and the initiation of large-scale welfare programs. One such of the latter was a program to subsidize historical research. Several researchers, either nostalgically or opportunely, prepared histories of the industry. A few of them were Briggs (1934) in the northwest, Saunderson (1936) in Montana, and Towne and Wentworth (1945) of the entire western range area. Perhaps anticipating the senior researchers were numerous graduate students who chose historical subjects for their M.S. theses, starting shortly after 1900 and reaching a peak in the 1930's.

Inventories of Range Resources and Type-of-Farming Studies

Concern with the closing of the open range also resulted in many studies of the apparently shrinking land base. Surprisingly little was written about the Taylor Grazing Service that came into being during this period. The major effort in inventorying resources was in drawing lines, lines to separate the range area from intermingled farming areas, and to describe the major physical and economic resources of farms and ranches in each area. Studies were made in almost all western states, including those by Clawson and others (1936) in Utah, Hunter and others (1935) in Colorado, and Johnson and Vogel (1934) in Idaho. The inventory effort was so large that teams of researchers were usually employed to complete the effort.

With completion of the inventorying effort and the close of World War II, results were combined with historical economic studies of ranch organizations, costs and returns in areas extending over several states. The Bureau of Agricultural Economics of the U.S. Department of Agriculture took the lead in this effort and the first of the annual studies dealing with ranch costs and returns were released. The early authors were Jones and Goodsell (1946) and Hochmuth and Goodsell (1948). These studies were unique for their time because they dealt with annual ranch data usually for two or more decades.

Taxation, Finance, Tenure and Appraisal

With increased private ownership of rangelands that took place in the 1920's and the closing of the open range in the 1930's, the great depression accelerated concern about land tenure. For example, land taxes became a major ranching cost during this period, particularly during depression. Tax studies were conducted in various states, with the geographical extremes being in New Mexico (Callaway and Cockerill 1935), and Oregon and Washington (Pingree 1930). Financing became a pressing problem for many ranchers, and studies were initiated by Jordan (1936) and Pelzer (1936).

Tenure studies were being made in the types of farming areas mentioned earlier. That is, the location and the common types of farms and accompaning ownerships were being described. But emphasis was needed to determine how rangelands might best be owned. The demand was met by authors such as Renne (1936) in Montana, and Loomer and Johnson (1949) and Kelso (1947) on federal lands.

Land prices first fell in the early 1930's and began their spectacular rise in the later 1930's. Land value and appraisal studies were needed. Making them were Clawson (1938) and Roth (1948).

Analytical Studies

The growing knowledge of range and ranch economics gained in the 1920's and 1930's resulted in studies of a new kind. These were studies of factors that affected production and income on cattle and sheep ranches as a primary focus. The normative aspects of optimization were based more on intuitive knowledge and experience rather than quantitative analysis (the earliest generation of econometricians were matriculating at about this time, and the second generation being born). Notable contributions highlighting the major factors affecting production levels and costs were made by Brennan and others (1933) in Nevada, and Nelson and Korzan (1941) in South Dakota.

Livestock Marketing

Passage of the agricultural Research and Marketing Act of 1946 reserving 20 percent of Hatch research funds for marketing stimulated interest in this subject in the late 1940's. A cooperative and significant effort by a new kind of organization, a western research technical committee, permitted researchers in several states to coordinate their efforts and conduct research with common objectives in multi-state areas. Previously this had been the exclusive domain of the federal government. A study of the shifts in trade of western slaughter livestock resulted (Western Livestock Marketing Research Committee 1950).

Range Improvèments

The appearance of studies specifically dealing with the economics of range improvements was a special feature of research during the period. The study by Pearce and Hull (1943) on artificial reseeding was among the first, and that by non-economists. A joint effort of the Bureau of Agricultural Economics (1949) produced a nationwide assessment of forage values, including western range reseeding.

Other Characteristics

The research up to the end of the decade was conducted by a group of researchers with several decades of experience, but lacking formal agricultural economics training. One event occurred that established the foundations for a profound change of this old guard. A document was published by the Secretary of Agriculture (1936) that dealt with the major range problems and their solutions, including social and economic functions. The range livestock industry responded with its own view of the range situation (Mollin 1938). Enough questions were raised by both documents that the name of the game in the future was to be "hard ball" played by highly-trained economists dealing with highly complex issues.

Again publications were mostly of the bulletin type with a few journal articles, proceedings papers and textbooks. Notable among the latter were the resources book by Clawson (1950). Economic tools used again were mostly descriptive budgeting with some insight based on experience.

THE RENAISSANCE PERIOD, 1950-1969

Research in the 1950's largely fell into three broad areas of marketing, range improvements and costs and returns by type of farming areas. By the 1960's, a wide variety of problems were being investigated. Perhaps most significantly, the new generation of economists entering the field in the early 1950's was not satisfied with the positive model and instituted studies utilizing the normative model. This group was highly trained, but lacked the decades of experience accumulated by such men as Clawson, Saunderson, Potter, Kelso, Burdick, Brennan and Vass. The research generally was scaled down to one or two special problems. Of particular importance was release of the first of a series of research methods in range and ranch economics (Hopkin 1954; McCorkle and Caton 1962). Another important element during this period was the establishment of a western research technical committee specifically assigned the task of doing research in range economics, and establishment of a Farm Foundation committee involved in the use and development of range resources. The latter committee was not charged with conducting research. Rather, they were charged with suggesting research needs, developing methodologies, and exchanging information on research methods and progress in their various states or organizations. The brief history of this group has been compiled (Committee on the Economics of Range Use and Development 1969).

Livestock Marketing

A very large number of publications were released during the two decades of this period on the subject of marketing. A special federal agency (the Agricultural Marketing Service) was established to coordinate efforts and make regional marketing studies. As marketing was a very large subject during the renaissance period, it deserves a history of its own. Consequently, only a few special studies will be cited. The areas of concentration were regional and state studies of market structure, conduct and (in a few cases) performance. Special studies were concerned with imported cattle (Seltzer and Stubblefield 1960), shrinkage (Harston 1959), and margins and costs (Agricultural Marketing Service 1956).

Range Improvements

The major economic research emphasis during the renaissance period dealt initially with range improvements and eventually with range enterprise analysis. This was not a happenstance event, but resulted from a deliberate, organized decision. The Western Agricultural Economics Research Council itself organized in 1948, formed a committee to foster research in the field of public land management on June 22, 1948 (Committee on the Economics of Range Use and Development 1969). The committee was called the Range Land Tenure Committee. Members consisted of Kelso of Montana (Chairman), Mason of Nevada, and Blanch of Utah. This committee fostered a project dealing with public land management, undertaken jointly by the Bureau of Agricultural Economics, U.S. Department of Agriculture, in California.

As a result of a report by Thomas of Utah, who was charged by the Council in 1950 to study research needs in the field of western range land and water resources, a committee proposal was developed by him in 1951. Thomas called a meeting at Logan, Utah in February 1951 to consider a program of research in the field of the economics of resource development. It was attended by about fifteen western agricultural economists. As a result of his recommendation, the Council appointed two standing committees, one of which was to deal with the economics of range resource development.

A motion was made and passed at a meeting of the Western Agricultural Economics Research Council at Logan, Utah on February 19-21, 1950 to discharge the Range Land Tenure Committee and replace it by a new committee, to be called "Committee on Development of Range Resources." According to a letter from Kelso, Vice-President of WAERC, dated April 14, 1951, which was addressed to Ackerman of the Farm Foundation, a formal application for grant of funds was made. Membership of the new committee was Kelso of Montana (Chairman), Upchurch of the Bureau of Agricultural Economics, Plath of Oregon, Blanch of Utah, and Mason of Nevada. It was indicated in the letter that the committee was not complete, with representatives yet to be named from Wyoming, Colorado and New Mexico, plus a member from the Division of Farm Management of the Bureau of Agricultural Economics. Upchurch was a representative of the Division of Land Economics. The committee appointed eventually consisted of Kelso of Montana, Broadbent of Utah,

Mason of Nevada, Pingrey of New Mexico, Plath of Oregon, and Upchurch of BAE.

The first meeting of the Committee, which was financed by the Farm Foundation, occurred on September 13-14, 1951 at Ogden, Utah. The agenda included a review of past activities (review of activities of the Range Land Tenure Committee), review of the report on the California Project, and a review of past and current research in the technologies of range land development. Other major items were proposals for research in land development, capitalization of public range land values into private land values, use and control of state-owned grazing lands, and methodology. Several participants were present representing the BAE, Forest Service, and the Bureau of Land Management.

The second meeting of the Committee occurred at Flagstaff, Arizona on July 18-19, 1952. Included on the program were discussions of range reseeding by Plath of Oregon, range improvement practices by Caton of Idaho, theoretical work in California by Upchurch of the BAE, pilot soil conservation districts by Mason of Nevada, and a review of current research needs by Baker of Montana, Hopkin of Wyoming, Burdick of Colorado, Pingrey of New Mexico, Seltzer of Arizona, and Hochmuth of the BAE in Utah. Also, research needs from the federal standpoint were reviewed by Heerwagen of the Soil Conservation Service in Albuquerque, Frandsen of the SCS in Portland, and Arnold of the Forest Service in Tucson.

The third meeting of the Committee consisted of a ten-day workshop at Logan, Utah dealing with research methods. The meeting took place from December 1-10, 1952. At this meeting, an organizational meeting took place and a draft was prepared for a new proposed regional research project, tentatively identified as RMA W-16-A, "Economics of Range Land Improvement."

Since the first meeting of the Committee, it met on the average of once a year for a total of nineteen meetings, terminating in the meeting at Tucson, Arizona on November 19-21, 1968.

Functions of the Committee were to: 1) Explore new areas of needed research in the general area of the economic use and development of resources related to range and range livestock production, 2) Explore methodological issues with respect to selected areas for research, and 3) develop bibliographies of publications dealing with use and development of range resources. Eleven proceedings issues were released.

Regional research projects generated by the Committee were Economics of Range Improvements (W-16), Economics of Range Resources Use (W-16 Revised), Economic Analysis of Range and Ranch Management Decisions on Western Livestock Ranches (W-79), and an Economic Study of the Demand for Outdoor Recreation (WM-59).

The latter project deserves special mention. The Committee and the Water Resources Committee, the latter also being a WAERC-Farm Foundation committee, independently recommended to the WAERC that a regional recreation research project be authorized. The first such project bringing order to the chaos of prior recreation research was authorized in 1966.

One interesting development during this period was a joint meeting with range scientists in Reno, Nevada in 1954. The economists present sought guidance from the range scientists on a meaningful measure of range productivity. Debate continued for three days, from October 20 through October 22. On the last day, the economists forced a vote among the range scientists, which were split into four groups, Utah, California, Texas and miscellaneous. By one vote a "majority" was reached and the animal unit measure has since been the standard unit of measurement. Feelings generated were such that this was the first and last time a region-wide group of range scientists were willing to meet with a like group of range economists.

Ranch Studies by Type-of-Farming Areas

Ranch studies by type-of-farming areas essentially were continuations of studies of organizations, costs and returns of groups of ranches in extensive areas thought to have common characteristics. Studies were conducted by the BAE and reported various statistics each year for a decade or more of "typical" or "representative" ranches (Gray and Baker 1951). Numerous studies were published in three major range areas -- Intermountain, Northern Plains and Southwest.

Analytical Studies

The renaissance period is noted for the first efforts to improve research techniques in range and ranch economics research. The eleven proceedings mentioned previously dealt largely with analytical techniques. Also, publications were released by Caton (1956) on budgeting, McCorkle (1956) on linear programming, Wallace and Judge (1958) on econometrics of the beef sector, Hopkin (1954) on optimal grazing, and a proceedings bulletin on risk and uncertainty (Great Plains Council 1955).

During the latter part of the period, the normative and predictive models were used in pricing and decision-making (Kearl 1963), estimating optimum cattle systems including range improvements (Barr and Plaxico 1961), and analyzing grazing fee impacts (Range and Ranch Management Investigations Group 1962). Economic impacts of drought decisions were initiated dealing either with drought predictions (Abel and others 1962), or adjustments to drought (Boykin 1964). The

internal rate of return equation was used extensively in range improvement investigations. A shift occurred during the period when it was decided that perhaps it was a mistake to study range improvements when the economics of the basic range livestock enterprise was imperfectly understood. Consequently, during the late years of the 1960's, the regional research committee constructed ranch budgets. During the last years of the period, ranch decision-making was a primary concern and studies were initiated utilizing Bayesian decision theory.

A wide variety of miscellaneous studies were released on the subject of state land administration (Wennergren and Roberts 1963). Incorporation received attention by Hubbard and Blanch (1961), and the first of a series of textbooks dealing with day-to-day ranch operations was published by Oppenheimer (1961). Important studies by Martin and Goss (1963) dealing with economies of scale of ranches, and by Lessley (1962) describing legal aspects of ranching, were unique.

Other Characteristics

By 1969, the inexperienced but highly-trained economists of the early 1950's had accumulated much experience and expertise on the subject of range and ranch resources, both at the state experiment station and the federal Economic Research Service levels. Part of this quality was due to individual effort and part to interactions when the group met together. A wide variety of new tools was utilized, including production economic tools, internal rate of return equations, linear programming, and Bayesian decision theory. A wide variety of media were used, with symposia and an annual compendium of papers at annual meeting taking the lead. The geographic emphasis was toward regional publications based on contributions from individual states, rather than the federal research group making investigations in two or more states.

THE ANALYTICAL AND PUBLIC POLICY PERIOD, 1970-1982

Withdrawal of regional funds and Farm Foundation support had disastrous impacts early in this period on the progress of range economics research. The communication lines were severed, particularly with termination of the regional research project. Consequently, most economists of the previous period drifted into a wide variety of other subjects and activities, mainly to assure continued financing of their research efforts. These other subjects and activities included recreation, energy and extension or administration. Increased concern about allocations of public land resources generated a revival about mid-decade with substantial resulting implications. Public policy decision-makers demanded that economics be woven into the fabric of their programs. When the response from those still in the field was underwhelming, the public agencies set about forming their own cadre of economists. These latter economists again lacked experience in the beginning, but are rapidly acquiring it in the crucible of environmental versus developmental conflicts. Meanwhile, the federal Economic Research Service underwent a series of rapid reorganizations and name changes (starting as far back as the early 1950's), the apparent goal of which was to be more responsive to national agricultural concerns and the Congress. In the process only one or two small viable groups concerned about range resources survived.

Most present-day economists are familiar with the history of range economics research for the past decade. Further, the analytical and public policy period has yet to be replaced by a new period, possibly in the 1990's. It is too early to objectively describe this period. Consequently, this section dealing with an on-going period will be abbreviated and few references will be cited.

An analysis of research in progress in 1971[2] revealed three major problem areas. They were organization and capital structure of ranching, cost reduction strategies, and benefit estimations. Summary of the five to nine subsections revealed that most attention in 1971 was being given by range economists to five areas of research: evaluation of optimum enterprise combinations, measurement of feed-forage relationships, analysis of the effects of range improvements, investigation of cost reduction and/or income increasing effects, and determination of comparative advantages of range livestock production over other uses of land. Areas receiving little or no attention were: determination of tenure combinations, identification of capital and credit restrictions in ranching, measurement of the role of management, identification of desirable capital and estate planning procedures, determination of optimal levels of input substitutions, and designing of improved data collection procedures.

A manuscript by Rafsnider and Skold[3] outlined several areas of research undertaken during the 1970's in the areas of range improvements, management and grazing systems.

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[2] Gray, James R. Las Cruces, N. Mex.: Review of research in progress, economics, 1971. A report to the Great Plains Range and Livestock Management Committee manuscript, 4 p, 1971.

[3] Rafsnider, G.T.; Skold, M.D. Fort Collins, Colo: Advances in regional and macro pasture and range economics in relation to a conceptual framework for grazed forage assessments, Rocky Mountain Forest and Range Experiment Station general technical report manuscript, 146 p, 1981.

Traditional Subjects

Wider use of computers and computerized ranch budgets led to several developments. Profitabilities of seeding rangeland or cropland to grass were investigated in several areas (Allen 1972; Cordingly and Kearl 1975). Brush control also received much attention by authors such as Murphy and Torrel (1972). A thorough analysis of problems in the sheep industry resulted in a series of publications authored by Gee and Magelby (1976). Anderson and Jemstedt (1971) evaluated the multiple economic effects of forage development and management in three major ranching areas using a case study approach. A model developed by Stevens and Godfrey (1972) specified effects on forage flows and use rates of specified investment paths in the Vail Project. Nielsen and Workman (1971) analyzed the impacts of federal grazing on state and county economics. The economics of grazing system was being investigated mainly by non-economists (Kothman 1975; Huss 1969). However, economists[4] began to take an interest in the subject mainly because of the time dimension in this kind of range decision-making.

Federal Range Policy

Advent of the environmental impact statements brought a new burst of activity, both in use of the traditional economic tools of budgeting and linear programming, but also applications of new tools to range resources and range policy. Perhaps the opening bell for participation in research dealing with public range policy was the work of consultants such as Nielsen of Utah in determining grazing fee levels as early as 1967. Since then there has been a great outpouring of benefit-cost ratios, input-output models, and linear programming results to estimate direct or indirect effects, optimum combinations of resources, and ranch budget generators. In at least one case, a special interdisciplinary organization was formed to deal specifically with public range policies that seemed to appear daily in the Federal Register. The Economic Research Service was not exempt from this activity, providing budgets for the agencies and preliminary current year budgets for the Congress (Economic Research Service 1981).

Some of the research resulting from the requirements of federal agencies to include economic dimensions to their background and decision documents will be discussed at this symposium.

Certainly, the numerous environmental impact statements and socio-economic profiles compiled by economists both inside and outside of the two major land management agencies have served as training documents for the uninitiated. By themselves, these efforts have given new impetus to many of the research methodologies initiated during this and the preceding period.

Special range policies deserve mention here. The wilderness program and the resource planning act program initiated by the Forest Service have generated much economic research. The stewardship program, the range improvement program, the unintended Sagebrush Rebellion, and the grazing fee program of concern to the Bureau of Land Management have and will bring forth others. The requests for economists to evaluate these problems have led in some cases to a more careful application of economic theory to some of these federal proposals and programs.[5]

Other Analytical Studies

The requirements of the complex biological system known as "range" in combination with a complex economic system involving "profit and decision-making" required much more complex analyses than were permitted by the tools mentioned to this point. Simulation analysis, with its ability to deal with complex systems, was developed in response to this need. One of the earliest management studies was by Halter and Dean (1965) for a large California range-feedlot cattle operation. The model did not include any biological processes. Other models dealt exclusively with biological processes. One that stressed management aspects of both the biological and economic processes was the dissertation by Abdalla (1980) involving a typical cow-calf enterprise in New Mexico over a 50-year period.

Other Characteristics

All of the academic researchers in the analytical and public policy period were highly trained and often with natural resource backgrounds in traditional agriculture, forestry or range. The research economists in the federal government had similar backgrounds. Many of the economists in the land management agencies, particularly those attached to field units, had master's degrees in economics or agricultural economics, and many lacked agricultural backgrounds. The mode of publication during the period has shifted from the academic arena to a vast outpouring of

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[4] Workman, John P; Nazir, Muhammad. Logan, Utah: An economic analysis of Bureau of Land Management grazing systems in the Intermountain area, Utah State University manuscript, 22 p, 1972.

[5] Obermiller, Frederick W.; McCarl, Bruce A. Logan, Utah: In search of reason: Issues and alternatives in the federal grazing fee debate. American and Western Agricultural Economics Association annual meetings manuscript, 46 p, 1982.

government preliminary drafts and final drafts that are usually very site specific. Meanwhile, conference proceedings and symposia papers abound. Reliance on primary data, studies which are very narrowly site specific, and tools which have been tested and retested together have not encouraged widespread publication of refereed journal articles, a publication media which has never been particularly popular in range economics research. The geographical emphasis has remained in the western range area.

CONCLUSIONS

Areas receiving most emphasis over the four time periods identified in this paper have been ranch budget studies and studies of costs of range improvements, livestock marketing, and in later years, public range resource allocation and policy studies. Areas receiving the least emphasis have been measuring the roles of management in range resource administration and livestock production, capital budgeting, research methodology and enterprise analysis. By and large, research efforts have been successful both when measured by the continuing level of demand for economic research results as well as the respect this sub-discipline has gained among ranchers, range scientists and public land administrators.

A notable failure has been the unfavorable attitude of mistrust with which range economists are regarded by that portion of the public concerned about land and environmental relationships. Another has been the failure to exploit a closer cooperative working relationship in many states and federal agencies between range scientists and range economists. Lastly, we have still the task of successfully persuading the range livestock industry as well as many range resource managers that success or failure lies as much in the business arena as in the strictly biological one.

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RANGE ECONOMICS - A NATIONAL PERSPECTIVE

Richard J. Crom and Melvin L. Cotner*

ABSTRACT: Major range economic problems are: achieving economic efficiency; maintaining productivity; and, providing access to public lands consistent with society's goals. The current demand for, and supply of, forage lands are presented to illustrate the need for a balanced research program between range supplies and livestock demands. Several researchable topics are presented, concluding with a suggested systems approach.

INTRODUCTION

Range and pastureland, including forest land available for grazing, is a major national resource. About two-fifths of the land area of the United States is devoted to these uses. As with all major resources of this kind, there is a national interest and a national perspective. There is strong interest at the Federal level concerning policies and programs relating to range and pasturelands, including research (Public Law 95-306).

We welcome this opportunity to share with you our interpretations of a national perspective regarding the Nation's pasture and range resources. Throughout the paper we use the term national interest and national perspective; by this we mean society's overall interest in how pasture and range resources are used, including who benefits and who gains from their use, and who bears the cost.

Our plan in this statement is to cover three areas: (1) a summary statement on the range economic problems and issues viewed nationally; (2) an assessment of the current situation and outlook regarding forage for livestock grazing; and (3) a national perspective for range economics research.

RANGE ECONOMIC PROBLEMS AND ISSUES

About 835 million acres of the Nation's land base is devoted to livestock grazing (table 1). Cropland pasture makes up about 9 percent of this acreage and is located in the Great Plains and Eastern regions of the United States. Grassland pasture, range, and the forest land grazed are located primarily in the Great Plains and Western regions, although about 90 million acres of pasture land and grazed forest land exist in the Eastern States (Forest Service report; Frey). Over 80 percent of the land area devoted to pasture and range use is in the 17 Western States; therefore, matters relating to pasture and range use, to a large extent, have a regional focus.

The Federal Government owns and administers about 60 percent of the rangeland in the 11 Western States--273 million acres on which grazing is allowed. Most of the Federal land is seasonally grazed, and much has a low carrying capacity. Thus, public lands account for only about 12 percent of the forage utilized in the 11 Western States and only 3 percent nationally (Public Land Law Review Commission report). The contribution of the public range as an input to the livestock sector nationally is relatively small, yet grazing privileges associated with public lands are critical to the health of the Western range livestock industry. The Western range is a major source of feeder cattle for Western and mid-Western feedlots. Given the high level of public ownership, Federal policies and programs have significant economic impacts.

The regional distribution of the pasture and range resource, the variability in carrying capacity and the multiple interest in the publicly owned land creates several important economic and institutional problems relating to pasture and rangeland use. The following summary is intended to provide a national view concerning these problems and issues.

Efficient Use of Pasture and Range Resources

From society's standpoint, pasture and range resources in both private and public ownership should be used efficiently. This implies utilization of pasture and range resources consistent with their economic productivity and their comparative advantage in use with other regions. A national issue concerns whether the livestock sector is making full economic use of existing forage resources and forage resource potentials across the country. Certain portions of tilled land may be better used in forage production, for instance, and may be a more efficient source of forage. The trend toward conservation tillage may influence the availability of forages and crop residues for livestock; these plant materials may have a more efficient use in protecting the soil. On Western rangeland, where other economic uses are minimal, the efficiency question relates primarily to management and investment decisions to increase the economic productivity of range. Finally, on publicly owned rangeland, efficient use of the

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*Chief, Animal Products Branch, National Economics Division, and Director, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. The authors wish to acknowledge the comments of John Fedkiw, Don Pendelton, Gale Walter, Lyle Schertz, Terry Crawford, and Ed Frandsen on earlier drafts of the manuscript. Tom Frey, Natural Resource Economics Division, ERS, supplied much of the data on the land base.

Table 1.--Major uses of land, 48 States[1]

Land use	1950	1960	1978
	Mil. acres		
Cropland, excluding cropland pasture	409	392	395
Cropland pasture	69	65	76
Total cropland	478	457	471
Grassland, including cropland pasture	700	698	663
Cropland pasture	-69	-65	-76
Total permanent grassland	631	633	587
Unclassified land in farms	45	45	36
Commercial forest land	484	501	[2] 470
Recreation	33	37	48
Urban	16	25	3/
Transportation	24	25	26
Wildlife refuges	9	9	18
Other land[4]	184	170	[2] 241
Total land area	1,904	1,902	1,897

[1]Source--See reference number 5.
[2]An estimated 172 million acres of both commercial and non-commercial forest land is grazed.
[3]Included in other land. A measurement of urban area comparable to that for 1970 probably would total about 45 million acres.
[4]Includes non-commercial forest land.

resource is influenced by the way the forage is priced to the user. As with all factors of production, water being a prime example, underpricing will result in overutilization--perhaps to the long-run detriment of the resource. Currently, the Congressional Budget Office is considering the option of a competitive bid process for public range to increase revenues and reduce the Federal deficit (Report to the Senate and House Committees on the Budget). Adjustments by the private and public sectors to make more efficient use of the pasture and range resource could influence the regional distribution of livestock production and pasture and range utilization.

Conservation of Pasture and Rangeland

Pasture and rangeland conservation has several dimensions. A primary concern has been the declining productivity of rangeland, an issue stemming from overuse. From an economic standpoint, arguments can be made that public grazing fees are below market values, and thereby encourage increased stocking rates that degrade range conditions. Stocking rates can be reduced, investments in range improvements can be made, grazing can be priced more in line with market values--all of which have bearing on the long-term productivity and the economics of rangeland use. In some instances, rangelands may be incapable of producing economic output on a sustained basis. In other words, any economic use may result in long-term degradation.

Another dimension of the pasture/range conservation issue concerns grassland conversion to cropland. Historically, grassland conversion on fragile lands has been a problem throughout the country, especially in the Western Great Plains. In the late 1930's after the dustbowl, highly erosive cropland was purchased by the Federal Government and placed in the national grassland program (Wooten). These lands are now administered by the Forest Service. After World War II, the Great Plains conservation program came into existence to also help shift cropland to grassland uses. This program was designed to provide technical and financial assistance on practices and management strategies to shift cropland into close-seeded vegetative cover (Kasal and Back). These programs still exist. Yet, grasslands continue to be converted to cropland, some through irrigation, but some simply go into dryland farming where the operator gambles on an occasional good crop year and high commodity prices.

From society's perspective, the Nation's long-term interest is best served if these lands are used in accordance with their production potential. As implied above, this may mean no use in the case of fragile range ecosystems, may require investments in range improvements or may result in shifts of marginal cropland to grassland uses. All of these adjustments imply economic impacts on the farmer and rancher. Further, many of the adjustments will not take place without technical assistance and perhaps financial support from the public sector.

Access to Rangeland

The access question relates primarily to the public range and who receives the right to use and benefit from its use. The range ecosystem provides many outputs. Domestic livestock grazing

is the primary economic use but wildlife, recreation and related uses have equally valid claims on the resource. While these uses are not wholly incompatible, issues exist on how the multiple demands are accommodated. One approach is to manage the resource to serve a dominant use such as livestock grazing while other uses become secondary (Public Land Law Review Commission). Another is to accommodate each purpose in accord with its value in use. Regardless of approach, economic trade-offs and opportunity costs play a significant role in these decisions.

Another facet of the access issue concerns not only who uses the range resource but what tenure the user enjoys. Control over use can involve ownership in fee simple, easements, and leasing. Leasing of public land often involves long-term arrangements. Some arrangements are considered to be in perpetuity, thereby inferring near-ownership characteristics upon the leasee. Institutional arrangements influence not only who benefits, but also who makes decisions concerning the use, conservation, and development of the range resource. The so-called "Sagebrush Rebellion" is an example of the access issue. The desire of the proponents is to shift the ownership and control of certain public lands in order to influence their use and achieve a different distribution of benefits from use.

From society's viewpoint the tenure arrangements that identify who benefits from the use of the range are important in tracing the equity and income distribution aspects of public range use. From an equity standpoint, using Jeffersonian principles, the social interest generally is best served if benefits are broadly distributed, and costs and benefits are guided by market forces to the extent possible. One can question if these principles are fully subscribed in current range resource use patterns and investment decisions.

To summarize, range economic problems, when viewed from a national perspective, have several facets: economic efficiency; maintenance of productivity; and, access by users that is consistent with society's goals. In our view these are important factors to be considered in future deliberation about range policies and programs; further, they imply a large array of issues needing economic research.

CURRENT SUPPLY OF AND DEMAND FOR PASTURE AND RANGE

The current situation concerning the supply of, and demand for, forages regionally and nationally serves as an important backdrop in identifying pasture and range economic needs. In this section, only the supply of, and demand for, domestic livestock grazing are considered.

National Forage Supply

In considering forage supplies, three categories of forage-producing land are considered--cropland pasture, permanent pasture and rangeland, and forest land used for livestock grazing (table 2).

As indicated earlier, most of the cropland pasture is located in the Eastern States, where cropping is more often an alternative; on the other hand, most of our permanent grasslands and ranges are farther west. In total, the 11 Western States contain a little over 50 percent of the forage land available, while another fourth is in the Northern and Southern Plains. Only 16 percent of the forage base acreage (mostly cropland pasture) is located in the 31 States east of the Missouri.

Most cropland is, essentially, all private ownership. However, the degree of public ownership of other land varies by region (table 3). In the 11 Western States, both permanent pasture and rangeland and grazed forest land are about even in degree of public ownership--just under 60 percent. The extent of public ownership is considerably less than this level in the Plains States; the national grasslands located in the four northern Plains States may give rise to the somewhat higher figure for permanent pasture and rangeland. Only the national forests in the East (mainly in the Southern coastal plains) constitute the small amount of public grazing in that region.

The total amount of land devoted to forage production has declined moderately since 1950. Even with this relatively fixed land base, forage supplies do vary from year to year. In most instances, the amount of precipitation available determines the short-term yield of forage. Cultural and management practices can, of course, enhance a more efficient use of the forage available, and may increase forage supplies. The moderate decline in pasture and rangeland since 1970 is associated with the increase in land cropped in response to rising export demands. To the extent this trend continues, forage supplies could diminish. On the other hand, continued crop surpluses, as we are now experiencing, could lead to even larger supplies of forage. Finally, our national land policy, particularly for the publicly-owned lands, affects the amount of forage that can actually be harvested by livestock from that acreage.

Currently, our pasture and rangeland produce forage for over 115 million head of cattle, plus 12 million stock sheep and their offspring. Range specialists estimate that grazing capacity could be increased by one-third through better management practices (Landsberg).

Demand for Forage and Range

Ruminants, be they beef cattle, dairy cattle, or sheep, are the major users of forage. On a national basis, beef cattle derive about 96 percent of their nutrition from forages, including harvested hay crops. This excludes cattle on feed. Sheep required about the same percentage of forage 15 to 20 years ago; last year, the forage base provided just over 90 percent of the nutrients for the stock sheep population. Dairy cattle nutrition has been trending more toward concentrates; dairy cattle relied on forage for 73 percent of their nutrients in 1965, but only 62 percent in 1981. We mention dairy cattle because dairying is becoming a growing enterprise in the West, particularly the Southwest. One of the major points that we wish to stress in this paper is the unique demand for

Table 2.--Forage land by region, 1978[1]

	11 Western States		2 So. Plains States		4 N. Plains States		31 Eastern States	
	Acres (mil.)	%	Acres (mil.)	%	Acres (mil.)	%	Acres (mil.)	%
Cropland pasture	8	11	16	21	10	13	42	55
Permanent pasture and range	359	61	112	19	73	12	43	7
Forest land, grazed	101	59	21	12	2	1	48	28
Total	468	56	149	18	85	10	133	16

[1]Source--see Wooten.

Table 3.--Extent of public ownership of forage base[1,2]

	11 Western States	2 So. Plains States	4 N. Plains States	31 Eastern States
	%	%	%	%
Cropland pasture	3/	3/	3/	3/
Permanent pasture and range	59	4	15	3/
Forest land, grazed	58	5	3/	6
Total	58	4	13	2

[1]Approximations based on reports and records of public agencies.
[2]Includes Indian Trust lands.
[3]Essentially 100 percent is private land.

Table 4.--Regional beef cow distribution[1]

	11 Western States		2 So. Plains States		4 N. Plains States		31 Eastern States		48 States Total
	Head (mil.)	%	Head (mil.)	%	Head (mil.)	%	Head (mil.)	%	Head (mil.)
1970	7.4	20	7.6	21	6.0	17	15.6	42	36.6
1975	8.3	18	9.6	21	7.8	17	19.9	44	45.6
1980	7.0	19	7.7	21	6.1	17	16.2	43	37.0
1982	7.7	20	8.3	21	6.5	17	16.8	42	39.3

[1]Source: Livestock and Meat Statistics, Stat. Bul. 522 and Supplements, ERS, USDA.

range and pasture grazing from our livestock population, and how that population can vary.

The carrying capacity of Western ranges is much lower than on eastern pastures. There has also been considerable feeling that the beef cattle population shifted to the Southeast during the sixties and seventies. The absolute numbers of beef cattle in the Southeast did increase during that time; in fact, the cattle population increased across the country. However, the regional distribution of beef cows, which reflects the distribution of the entire beef cattle herd, has not changed much over the past 12 years. Since 1970, the 11 Western States have contained approximately 20 percent of the Nation's beef cows (table 4). Another 38 percent has been held in the Plains States; the southern Plains plus the southern half of the northern Plains can almost be termed the "cow-belt" of the Nation. Finally, just over two-fifths of the cow herd is in the Eastern States which, of course, involves the expansion in the Southeast.

The distribution of stock sheep leans heavily toward the 11 Western States; now, 50 percent of all stock sheep are in this region (table 5). Another third of stock sheep is located in the Plains States. The distribution of stock sheep has trended away from the Eastern States and seems to be more concentrated in the areas west of the Missouri.

The location of both cattle and sheep appears to have been rather stable over time. The absolute levels of the beef cow population have varied over the production cycle in all regions; but there has been less variation in the cow herd in the West than in the East.

Livestock demand for range and pasture has varied with the net returns from livestock production. Several cost and returns studies have been advanced in recent years that show lower costs in the Range States than farther east, particularly in comparison with the Eastern States, where substantial fertilization is required (Van Arsdall). Another area that has not been addressed is the comparative advantage that livestock producers probably enjoy in the West compared with the eastern region.

Obviously, the overall demand for beef, lamb, and all meat affects the size of the Nation's cattle and sheep population. Currently, we may be in a state of transition and data are not yet available to indicate whether meat demand is increasing, stable, or decreasing. If demand rebounds after this recession as incomes increase, then pressure for grazing an expanding herd could be put on all regions. But if consumer tastes turn toward other foods, overall grazing demand will decrease. However, if the West enjoys a comparative advantage in beef production (mainly due to limited alternative uses), then most of the adjustment may be expected in other regions.

NATIONAL PERSPECTIVE FOR RANGE ECONOMICS RESEARCH[1]

The preceding discussion of range problems and issues and the situation and outlook discussion set the stage for identifying economic research needs. We will not attempt to cover a complete research agenda; instead we will focus on certain priority areas of economic research we feel would have high pay-off when looking at pasture and range as a national resource. The priority areas cover range demand, range supply, range forage pricing, and national modeling work which incorporates the supply and demand information in analytic systems to examine national pasture and range issues discussed earlier.

In 1980, staff in the Natural Resource Economics Division of ERS conducted a telephone survey of university and government offices in the Western States, including Texas, to determine the amount of range economics work underway. The survey revealed that less than 15 scientist-years of work were devoted to ranch management and range resource economics research. Federal agencies listed 3 scientist-years of effort. Much of this work is directed to ranch management problems, therefore the amount of work specifically directed to

[1]The economics research needs section of this paper draws on ideas developed in a range economics research needs statement prepared in 1980 for internal USDA review entitled, "Economic Analysis of Pasture and Range Resource Use" by Joe Barse, Mel Skold, Giles Rafsnider, and Mel Cotner.

Table 5.--Regional stock sheep distribution[1]

	11 Western States		2 So. Plains States		4 N. Plains States		31 Eastern States		48 States Total
	Head (mil.)	%	Head (mil.)	%	Head (mil.)	%	Head (mil.)	%	Head (mil.)
1970	8.4	48	3.5	20	1.8	10	3.7	22	17.4
1975	6.0	48	2.6	21	1.3	11	2.5	20	12.4
1980	5.6	50	2.3	21	1.2	11	1.9	18	11.0
1982	5.7	50	2.4	21	1.2	11	2.3	18	11.6

[1]Source: Livestock and Meat Statistics, Stat. Bul. 522 and Supplements, ERS, USDA.

uestions outlined here is relatively small. The epartment has considered expanding its range conomics work but in an era of tight budgets and ompeting priorities, range economics research nitiatives have rated low.

esearch on Range Supply

o What is the aggregate supply curve for the western range? Is it completely inelastic with weather being the principal shifter, or are other variables involved giving it a limited slope?

o What are the costs and benefits associated with cultural and management practices; and what level of investment can be justified for range improvement practices? Too often, many recommendations are made on the basis of physical efficiencies involved, without considering the economic efficiencies which may or may not be gained.

o What is the carrying capacity in economic terms of selected pasture and range resources? Do decreased stocking rates increase overall forage productivity? Is there a change in costs as stocking rates and intensity of use change? Changes in management practices may be warranted at various stages of the cattle cycle. Oregon State has done some recent work on this (Nordbloom).

o How does substitution of harvested and grazed forages affect livestock production costs? This is also associated with the stocking rate question.

o How do price support programs and crop profits affect the shift of grasslands to cropland through irrigation development?

Research on Demand for Range

Since pasture and rangeland are relatively fixed, considerably more effort should be spent in looking at the demand for the forage it produces. In 1980, the Forest Service projected a 35-percent increase in the demand for range grazing by the year 2000, and a 41-percent increase by the year 2030. Questions now are:

o What is the current livestock population on the range, and how many are expected in the future? This centers, first, on estimation of livestock numbers that will be grazed. National and regional projections as they deal with profitability over the production cycle is one area of interest to livestock and range economists. Coupled with this are studies of costs and returns on individual ranges. While USDA prepares national and regional estimates of costs and returns from livestock production, we think that research on range demands could be better accomplished through more localized adaptations of such studies. In recent years, the Forest Service has contracted with ERS for linear programming analyses of individual range resource situations to determine the marginal values of additional forage (Gee).

o Will the overall demand for meat including beef and lamb increase, decline or remain near current levels?

o Does the Western range enjoy a comparative and/or absolute advantage over other regions for livestock production? ERS regional costs and returns budgets for beef cattle (Van Arsdall) indicate that a comparative advantage and, probably, an absolute advantage exist, but this should be documented. If so, the demand for grazing should remain high, even if the overall demand for meat decreases, as may be the case.

o Can range livestock be marketed more efficiently, thereby increasing producer returns? Any improvement in marketing practices should increase the demand for western range grazing.

Range Pricing

The grazing fee issue has been of paramount importance in the West since almost the turn of the century. Currently, work is being undertaken to advise the appropriate Secretaries of Interior and Agriculture and the Congress of what grazing fees should be after 1985 (Public Law 95-514).

o What are the variables that affect the value of range for grazing--a major factor that perhaps should influence rental rates?

o What is the pricing process for private range? How does the "price-discovery" mechanism operate?

o How should public range be priced?

Some work needs to be theoretical in nature, and then that theory put into practice to develop workable relationships. Also, the impact of various pricing levels and policies needs to be assessed, both in terms of equity to the user and owner, and in terms of the effect on livestock production.

Systems Modeling

Pasture and range forage supply and demand relationships need to be integrated into a national analytic capability to assist in the evaluation of regional comparative and absolute advantage in producing forage for livestock grazing. This capability would help identify economic efficient grazing strategies, particularly if such analyses could be matched with similar livestock and feedgrain models. Models containing range forage supply and demand relationships also would be useful in measuring the trade-off and complementary relationships between the economic and environmental uses of the pasture and rangeland resource.

The Department has new resource management and conservation program appraisal and planning authorities (Public Laws 94-588, 95-102, 95-306) which require improved information on resource issues. The economic information on pasture and range resources, both on public and private lands, is important to the assessment and planning activities required by these Acts. The needed economic research, in particular the systems modeling work outlined above, would be highly useful to those with responsibility to carry out the provision of these Acts.

SUMMARY

In this short period of time, we have tried to help set the stage for this symposium, giving a notion of the importance of the range and pasture resource and, then, assessing both the current supply and demand situations with a comment on some of the major determinants of the supply of forage and the demands for forage. We would like to reiterate that more attention needs to be given to the development of a balanced program of pasture and range economic research that emphasizes the demand for, as well as the supply of, forage. Further national studies are suggested to examine the linkage of forage supplies, non-livestock demands, and the livestock sector.

Finally, we have attempted to raise several researchable issues for your consideration in discussing economic research needs. Work on range supplies should involve both our land resource economists and those working in livestock supply. Demand research should focus both in terms of projections, in terms of models, and work in pricing efficiency. We hope this will be beneficial for your deliberations of the next few days in outlining an appropriate program of range economic research.

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MEAT - AN END PRODUCT FROM RANGELAND

CURRENT PRODUCTION AND CONSUMPTION SITUATION AND IMPLICATIONS*

W. Gordon Kearl and Patricia D. Hoye**

'e purposes of this paper are:

to present some data on range livestock and ke some inferences about production from the ngeland-harvested forage complex of 17 western d plains states;

to discuss meat consumption trends and esent situation, nationally; and,

attempt to draw some inferences about direct- ns for research.

the history of range economics research the -16 Project related to range improvement stands it as a case of placing the cart before the horse. ien that project was undertaken sound studies of :onomics of ranching were not available to use as ise or benchmark situations for the range improve- ents research. It is difficult to think of range search except in the context of the entire mplex of livestock, range and harvested forages, iough some lands can be called range and only used r wildlife.

iis paper is based on two assumptions: (1) the iestion of range research needs for the next 20 ears, or so is being addressed at this conference; id, (2) the concern is about all rangelands, not ist the Public Lands.

IVESTOCK INVENTORIES AND PRODUCTION

attle Inventories

attle inventory numbers of the 17 western and great lains states are summarized in Table 1 and Appendix able 1 for states and regions as follows:

acific	Rocky Mountain		Great Plains	
alif.	Ariz.	Nev.	Kansas	Okla.
re.	Colo.	N. Mex.	Neb.	S. Dak.
ash.	Idaho	Utah	N. Dak.	Texas
	Mont.	Wyo.		

* This paper is part of the research effort of Inter-regional Research Project IR-6.

* W. Gordon Kearl is Professor and Patricia D. Hoye is Research Associate, Division of Agricultural Economics, University of Wyoming, Laramie, Wyoming.

The dairy cows and replacement heifers are nearly equal to corresponding classes of beef cattle breeding stock in California. The dairy component is about 56% of the beef breeding stock component in Washington, between 20% and 30% for Arizona, Idaho and Utah, 16% for Oregon, 5-10% for nine other states and only about 2% in Montana and Wyoming. If other components of the cattle inventory are considered, the proportion which is dairy is further diminished. The contribution to beef production from the dairy component consists of cull cows and dairy calves grown out for beef. The latter might be considered to have left the dairy sector and entered the beef component when the decision was made to grow them out.

Dairy cattle consume a large amount of feed. However, given the high use of concentrates for dairy cattle, total roughage consumption per cow is probably less than for beef cattle.

Percentage calf crops born calculated for cows that have calved or cows plus replacements are as follows:

	Calf crop as a percent of	
Region	Cows that have calved	Cows plus replacements
Pacific	89.8	70.7
Rocky Mountain	92.6	77.5
Great Plains	90.5	77.8
17 States	90.9	76.8
United States	90.5	74.7

Calf crops born are only about 90% of cows and heifers that have calved or about 77% of cows plus replacements. The effect of the dairy component can be seen in the pacific region. The true percentage calf crop born lies somewhere between the extremes and perhaps about mid-way, or around 84 to 86% as an "honest percentage" calf crop born, considering only cows and replacements actually expected to calve.

Although data are not included, death losses of calves are in the 6 to 10% range, reducing the honest percentage calf crop weaned to something less than 80%.

Research directed toward the improvement of reproductive efficiency is a significant need and that aspect of range research should not be overlooked. Three specific aspects include research in development and use of flushing pastures, range nutrition for the last trimester of pregnancy, and the effects, either positive or negative, of grazing systems and grazing management techniques on reproductive performance.

About 23 million calves are born in these 17 states. Allowing for death loss and use for replacements, the input to beef production probably amounts to about 17 million weaned calves and 3 million cull cows. Most of those represent production from a very significant input from rangelands and pastures. The use of rangelands and pastures for growth after weaning is indicated by the calves under 500 lbs. and steers and other heifers over 500 lbs., about 40% of them not in feedlots.

Production of Cattle and Calves

Production and value of production of cattle and calves in the western and plains states are summarized in Table 2. Production and value of production, unlike cash receipts or value of marketings, takes into consideration and adjusts for effects of inventory changes and resale of purchased animals. Averages for 1972-80, which includes portions of both sides of the cycle, are

Table 1. Cattle inventory numbers in the western and great plains states, 1972-81 averages, January 1. (1,000 head)

Item	Regions				
	Pacific	Rocky Mountain	Great Plains	Region Totals	All U.S.
Dairy cattle					
1/ Milk Cows	1,108	454	1,011	2,573	11,132
2/ Replacements	421	189	291	901	3,990
Sub-total	1,529	643	1,302	3,474	15,122
Beef cattle					
1/ Cows	2,004	5,517	15,224	22,745	40,535
2/ Replacements	421	973	2,349	3,743	6,874
Sub-total	2,425	6,490	17,573	26,488	47,409
3/ Other heifers	329	924	2,941	4,194	7,141
3/ Steers	1,485	2,032	6,451	9,968	16,566
4/ Calves	1,817	3,571	11,177	16,565	31,456
Bulls	147	336	897	1,380	2,596
Total beef cattle	6,203	13,353	39,039	58,595	105,167
All cattle and calves	7,732	13,996	40,341	62,069	120,290
Calves born	2,796	5,531	14,698	23,025	46,735
Cattle Fattening					
5/ Cattle on feed Jan. 1	1,144	2,036	5,372	8,552	12,826
Fed cattle marketed	2,199	3,790	11,943	17,932	24,242

Sources: "Livestock and Meat Statistics." Economic Research Service/Statistical Reporting Service/ Agricultural Marketing Service Statistical Bulletin No. 522, U.S. Department of Agriculture and Annual Supplements.

"Cattle: Final Estimates for 1976-79." Economics and Statistics Services. Statistical Bulletin No. 655, U.S. Department of Agriculture.

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1/ Cows that have calved.
2/ Replacement heifers over 500 lb.
3/ Other heifers or steers over 500 lb.
4/ Calves under 500 lb.
5/ Included in categories above, also.

Table 2. Average production and value of production of cattle and calves, western and great plains states, 1972-1980.

Region	Production (Millions)		AUM	Production per AUM	
	Amount	Value	Equivalent	Amount	Value
	(lb)	(dollars)	(thousands)	(lb)	(dollars)
Pacific	2,718	1,195	92,784	29.29	12.88
Rocky Mountain	5,551	2,554	167,952	33.05	15.21
Great Plains	15,002	6,791	484,092	30.99	14.03
17 States	23,271	10,540	744,828	31.24	14.15
U.S.	40,754	17,645	1,443,480	28.23	12.22

not greatly different from a short term average for more recent years or of the current levels. Production for these 17 states amounted to 23.3 billion lb., or about 100 lb. of liveweight produced per capita of the national population.

Prices, even at current seemingly depressed levels, are 33% to 40% above average prices for 1972-80. That has a proportionate effect on value of production, which at present is probably 33% to 40% greater than averages shown.

The importance of the industry in these 17 western and plains states can be judged by its $10.5 billion in average value of production through 1972-80 and probably $14 to $15 billion in 1982.

Animal-unit-month (AUM) equivalents, production and value of production per AUM equivalent are also summarized in Table 2, with detail shown in Appendix Table 2. For this purpose AUM equivalents were calculated by multiplying all cattle and calves shown in Table 1 by the number 12. That is analogous to use of a coefficient of 1.0 for all animals over six months of age. There is a limited amount of fall calving in these states, but most animals in the January 1 inventories, including calves under 500 lb., are over six months of age. Also, most remain in the inventory for 12 months or if removed they are replaced by the next crop moving up.

The inventory of cattle in feedlots was counted only once for calculating AUM's. Given high feed use, a higher coefficient may be appropriate, but for much less than 12 months for a particular group. Turnover through the feedlots is indicated by the ratio of cattle marketed to cattle on feed in principal feeding states. If an allowance is made for that, use of 1.0 coefficient for the January cattle on feed inventory is quite reasonable.

Obviously there are simplifications in calculation of AUM's. Use of a different and perhaps more accurate method gave AUM equivalents for cattle in Wyoming at 5.7% less than use of this simple method (Kearl 1980. Comparable results might be found in other states with small dairy or feedlot industries. Where those industries are more important the comparison between the simple or more complex methods may be worse, or quite possibly better than for Wyoming.

Given qualifications above, liveweight production per AUM equivalent is in the range of 25 to 35 lbs and mostly within 30 plus or minus 3 lbs. Noticeable exceptions are Arizona and Colorado where feedlot industries are larger than in other states, relative to the breeding herds.

Value of production per AUM equivalent is mostly within $11 to $16, with the same notable exceptions mentioned above. At 1982 prices, value or production could easily be 33 to 40% higher than shown. Production includes gain on yearlings held and some portion of production from cow sales. Montana, Nevada and Wyoming are three states with minimal dairy and feedlot effects. They have weighted average production and value of production as follows:

Montana, Nevada and Wyoming

Basis	Production (lb)	Value of Production ($)
Per AUM	27.48	$ 12.49
Per AU (AUM x 12)	329.76	149.88
Per cow and replacement	535.94	241.73
Per cow only	634.41	286.14

For comparison, taking 20 lb of hay per day or 600 lb per month as an AUM equivalent, the 1972-80 average October price of hay in Wyoming was $14.81 per AUM equivalent, which is $1.71 higher than the value of production (Appendix Table 2). Considering barley at 75% total digestible nutrients (TDN) and assuming 300 lbs TDN as an AUM equivalent then 400 lb of barley would be an AUM equivalent and cost $17.12 at 1972-80 average October prices in Wyoming. Relationships in other states and with other forms of supplemental feeds would likely be similar.

Obviously, if supplemental feed costs exceed a pro-rated value of production ignoring all other costs during the supplementation period then it will be necessary to have other times of the year when all costs are far below pro-rated value of production. That is the important role of rangelands.

It is difficult to specify the portion of production which comes from pastures or rangelands even for states such as Montana, Nevada and Wyoming where production from dairy or feedlots is negligible. Obviously, most of the animal gains occur on pastures and rangelands during periods of active grass growth. However, within any particular area and technology, growing forage and dry forages, whether hay or winter ranges and other supplemental feeds, tend to be used in relatively fixed proportions. It is difficult to differentiate among forage or seasonal range types and attribute different production to different resources when each seasonal forage resource is required in order to have any output from the breeding herd stage of production.

Many of the seasonal feed resources are substitutable or interchangeable in one direction at least. Spring, summer and fall range resources are often interchangeable, and even interchangeable with winter ranges. Obviously, high elevation ranges in national forests cannot be substituted for spring, fall or winter forage supplies. However, one winter forage, hay, can be substituted for summer forage by keeping livestock in drylot. For that reason, one might be suspicious of models that attribute to any range type or seasonal use a marginal value productivity per AUM far above the price of hay per AUM equivalent. When that happens, as it sometimes has, perhaps the model has not allowed for transformation from one to another seasonal feed, or for purchase of hay.

Sheep, Lambs and Wool

Inventories of sheep and lambs are summarized in Appendix Table 3. Unlike the cattle numbers cycle, sheep numbers have been declining and the 1972-81 averages are considerably above current levels.

AUM equivalents for sheep were calculated using a coefficient of .2 per sheep month or 2.4 AUM's for stock sheep and .2 for 2.5 months or .5 AUM for sheep and lambs on feed. There are far less sheep than cattle in the region, with much smaller requirements. Consequently, the total AUM equivalent requirement is only about 24.7 million for sheep, compared with 745 million for cattle.

Total liveweight production for the 17 states amounts to about 620 million lbs of lambs and sheep, 101 million lb of wool and about $330 million in combined value of production (Appendix Table 3). Value of production does not include government support payments for wool production.

Value of production of lambs and wool per AUM equivalent are about the same as previously indicated for cattle (Appendix Table 4).

Value of Production or Value Added

Kunz and Purcell have made studies estimating value of production and value added by production of various agricultural commodities in 1979, including three studies with information pertinent to the 17 states being considered in this paper (Kunz and Purcell 1981, 1982a, 1982b). Introducing their studies they said:

> "The concept of 'value added' has been used in manufacturing and fabrication, but generally not applied to the farming sector. However, as crop and animal production activities approach manufacturing in character, the concept of 'value added' becomes highly useful in evaluating the relative importance of farm production activities. Industrial inputs and interfarm transfer of inputs are becoming progressively more important in the farm sector.
>
> "Wealth created in farming accrues in commodities created by specific production activities. All production activities require personal initiative (labor and management), a land base and durable capital goods (buildings, machinery, equipment, tools, etc.). Also, most production activities consume or modify other products that contain market determined values (prices). The latter products, used in this production process and replaced each production cycle, are defined as consumed inputs. The difference between the value of the final production and the value of the consumed inputs (the value added) accrues to the local economy as returns to labor-management, the stock of durable capital, and the land base.
>
> "Such returns (value added) may be disbursed as payments for hired labor, durable capital, land improvements, property and other taxes, interest on borrowed funds, insurance, overhead, etc., or retained as profit (loss). Profit (loss) is a return for undertaking a risk bearing activity (enterprise)....
>
> "Estimates of 'value added' or value created ... are those values created by on-farm production processes....Value added or created is a more appropriate measure of the value of a particular production activity than is gross value of the product or cash receipts. Gross value contains considerable double counting of the value created by farm production activities while cash receipts shifts the emphasis to the final product."

The final product, especially livestock, is in fact credited for much value of production created by crops consumed. Value added credits livestock for value produced by range or other unharvested forages, but not for value of crops consumed.

Describing procedures Kunz and Purcell said:

> "Estimates of area seeded (crops), inventory (animals), yield (crops), production, farm prices (price received by producers), aggregate value (value of production), cash receipts by commodity, and other data are published on a continuing basis by the Statistical Reporting Service and the Economic Research Service of the U.S. Department of Agriculture....
>
> "The Economic Research Service of the U.S. Department of Agriculture and most State Agricultural Experiment Stations and Extension Services develop production budgets. These budgets contain information on the quantity and price of inputs (products) consumed in the production activities (commodities). A factor for "value added" or value created was derived from each budget. (F(VA) = 1-VCI/VP; F is the factor for value added, VCI is the value of consumed inputs, and VP is the value of the product for the specified budget.) The state aggregate value for each commodity (enterprise activity) was adjusted by the factor for value added to obtain the estimate of value added or created by the production activity."

One criticism which can be directed at this value added work is that it is for a single year, 1979. The volume of work required in this study of all 48 states precluded use of several years. The year used, 1979, was the most recent for which data were available, but was also a year of unusually high prices for cattle, sheep and wool. Hay and some other crop prices were strong based on Wyoming as an example, but not higher than in some previous years such as 1974 and 1976.

Value added by "livestock", hay and all other activities are summarized in Table 3 and Appendix Table 5. Livestock includes cattle, sheep and wool. It does not include milk production, swine or any type of poultry. Hay is reported because it is the major harvested forage input for beef cattle and range sheep. Obviously, some hay is used by dairy cattle and some in feedlots. Most of the hay can only be used by beef cattle, with a little by sheep. The calculation of value added

y livestock is net of value added by hay, but ithout the livestock there would be little value dded by hay. With reduced rangelands use there ould be continued use of some hayland and conver-ion of other to grazing, but only with great eductions in value added.

he Pacific region is dominated by California, ith much of the value added from production ctivities other than cattle, sheep, wool or hay. he livestock-hay complex did account for 17% of alue added in agriculture in the Pacific region n 1979.

'able 3. Relative importance of livestock and hay roduction activities in the farm sector, various tates and regions, 1979.

Region and 'roduction Activity	Value Added: Total $ Million	Value Added: Percent of Total
'acific		
Livestock	921.237	10.1
Hay	624.868	6.9
All Other	7,538.962	83.0
Total	9,085.067	100.0
꞉ocky Mountain		
Livestock	2,134.477	37.8
Hay	852.403	15.1
All Other	2,653.067	47.1
Total	5,639.947	100.0
'lains		
Livestock	5,463.997	29.6
Hay	1,277.057	6.9
All Other	11,731.251	63.5
Total	18,472.305	100.0
3 Regions Total		
Livestock	8,519.711	25.7
Hay	2,754.328	8.3
All Other	21,923.280	66.0
Grand Total	33,197.319	100.0

ources:

Kunz, Janice J. and Joseph C. Purcell. 1981. 'Value Added (Created) in Southern Region USA Agriculture." IR-6 Information Report No. 34. Interregional Cooperative Publication of the State Agricultural Experiment Stations. August.

Kunz, Janice J. and Joseph C. Purcell. 1982. 'Value Added (Created) in North Central Region USA Agriculture." IR-6 Information Report No. 58 Interregional Cooperative Publication of the State Agricultural Experiment Stations. April.

Kunz, Janice J. and Joseph C. Purcell. 1982. 'Value Added (Created) in Western Region USA Agriculture." IR-6 Information Report No. 59 Interregional Cooperative Publication of the State Agricultural Experiment Stations. July.

In the Rocky Mountain region livestock and hay account for about 53% of value added. Data for Montana, Nevada, Wyoming and New Mexico are as follows:

Montana, Nevada, New Mexico and Wyoming

	Value Added: Total $ Million	Value Added: % Total	Value of Production: Total $ Million	Value of Production: Percent of Total
Livestock	1,103.792	49.9	1,625.506	50.0
Hay	411.447	18.6	523.078	16.1
All Other	695.193	31.5	1,100.266	33.9
Total	2,210.432	100.0	3,248.850	100.0

Obviously these states are heavily dependent on the livestock-hay-forage complex, with about 68% of the value added from these sources. Wyoming and Nevada have about 80 and 86% of value added by livestock and hay. In the Rocky Mountain region only Arizona and Colorado had higher value added from other products than from livestock and hay.

Among six plains states value added from livestock and hay amounted to about 36% of the total. The percentages for individual states were from less than 30% for Kansas and North Dakota to about 50% for Oklahoma and South Dakota.

Sources of Carrying Capacity

Although it is difficult to attribute production to different resources, it is possible to estimate sources of carrying capacity using Wyoming as an example:

Wyoming	AUM Equivalents (millions)
Requirements of cattle and sheep	21.0
Sources of forage resource	
Hay, 1.88 million tons at 3.0 to 3.3 AUM equivalents per ton	5.6
Hay aftermath, 1.1 AUM per acre	1.2
Other crop aftermath	1.0
Public rangelands active use (approx.)	2.4
Private rangelands, farm waste, sub-marginal wet meadows, etc.	10.8

Hay is sufficient for about 27% of total requirements. Aftermath provides about 1.0 AUM or a little more per acre of hay harvested. Aftermath from other crops is slight, except for sugar beet tops and a small amount of corn harvested for grain. There is a significant carrying capacity on wetlands that are sub-marginal for hay production, but very little of bona fide improved irrigated pastures.

Public lands provide about 11% of the total requirement or 20% of the total from rangelands. A "best" estimate is about 10 million AUM from private rangelands. That is about .3 to .33 AUM per acre, or about 3.0 to 3.3 acres per AUM, which is consistent with the average productivity of privately owned rangelands in the state.

Data for two other states with small dairy industries, Montana and New Mexico, are as follows:

	Million AUM Equivalent	
	Montana	New Mexico
Required for cattle and sheep	37.3	20.2
Provided from hay, at 3 AUM per ton	10.4	3.2
From other sources	26.9	17.0

Hay supplies about 28% of required capacity in Montana, but only about 16% in New Mexico. No further partitioning between aftermath and public and private ranges will be attempted for these states. Montana may be quite similar to Wyoming in total. Because of season-long use, rangeland in New Mexico may contribute a higher percentage of carrying capacity than in Montana or Wyoming.

Ranch Costs

Occasionally costs become the focus and reason for predictions of industry decline. When considering costs it is important to carefully specify costs included. Data on costs and returns per cow for a cow-yearling ranch in Wyoming are summarized below:

	Per Cow	
	1978-81	1981
Receipts	$393	$355
Cash costs (debt-free)	210	244
Net cash income	183	111
Depreciation	43	45
Net ranch income	140	66
Allowance for operators labor and management	57	59
Return to capital	83	7
Interest on working capital	96	134
Return to fixed capital	(13)	(127)

Through the years 1978-81 a ranch free of debt or with only a small debt could produce a reasonable return to operators labor and management, but no return to fixed capital. Land appreciated about 35% during the period. In 1981 and surely in 1982 returns are much reduced.

If the operation is treated as an enterprise, as is sometimes done, charges for operators labor and management, working capital used, and for land result in large losses. It must be recognized that cost items to the livestock enterprise for labor, management and capital are returns to the operator and his capital. Alternative opportunities for operators labor and management, and certainly for the land resources are limited. Most of those costs are fixed. Theory teaches that production will continue in the short run if variable costs are covered. We should not project large changes in resource use yet.

Everyone doesn't make a profit every year in a perfectly competitive free enterprise system. That has been true of operators of small and large business, buyers of penny stocks and petroleum or oil well service stocks, etc. Livestock feeders have a history of operating above break-even levels less than half the time. Should more be expected in the range livestock industry stage of production? Are there any principles or logic to support arguments for guaranteed returns?

Implications

Occasionally one hears that the livestock industry in the west cannot compete with that in the mid-west or southeast. A few things seem clear:

(1) there is a very large resource base for production of hay and range forage in these 17 states;

(2) there are few bona fide alternative uses for most of these resources, even conceding the possibility of recreational uses on some;

(3) the ruminant animals are the only animals capable of utilizing the forage from these types of resources; and,

(4) much of the resource base, especially that from the east side of the Rocky Mountains to the west side of the Sierra Nevada Mountains is ill-adapted to intensive use of labor and capital inputs, in spite of federal agency talk for the last 16 years or so about intensive management;

(5) privately owned rangelands provide much more o the forage resource than do the publicly owned lands, are generally more productive of forage and more amenable to management. Major research emphasis should be toward management and improvement of this resource.

The indications to a non-modeler are that the industry will go on, utilizing the resources, perhaps with some modifications and improvements in management and technology, but without any great changes in productivity of the basic resource.

CONSUMPTION

Production has been treated on a regional basis, though it occurs nationally. Consumption will be treated on a national basis.

A number of statements heard at a recent beef profits conference in Denver bear repeating.[1/] On thought expressed by a few speakers was "the beef cattle industry is now a mature industry. We shouldn't expect a great deal of further growth." The statement is probably true if the entire meat industry is considered. Total consumption per capita is as high or higher than it has ever been (Ikerd 1982). Ikerd's analysis also indicates the demand for all meats has been "consistent" (not shifting) through the last 20 years. There has been an increase of 30% in total meat consumption per capita but a 43% decrease in income deflated prices all occurring on a non-shifting demand curve for all meat.

[1/] National Beef Profit Conference. Sponsored by the National Cattlemen's Association, Denver, Colo., June 27-29, 1982. The proceedings from that conference are not yet available. Some useful quotations are remembered, but cannot be identified with individual speakers.

The beef industry is concerned about shifting demands for beef and a loss of market share. Pork was the most popular meat in the United States during the first half century (Ikerd 1982). Beef was higher priced, less plentiful and much was not the high quality we have now, but grass fed or cull cattle, including dairy stock. Chicken was for special occasions.

Beef surpassed pork during the 1950's, and still brought premium prices, giving statistical evidence of a shift in consumer preferences. High quality from greater grain feeding was probably a factor. Consumption of chicken also increased greatly. That is more likely a response to much lower relative price, and probably the result of production efficiencies of the poultry industry, not an indication of basic change in preference.

Beef is being more seriously challenged since the mid-1970's. Retail pork prices averaged almost 75% of retail beef prices from 1962 to 1981, but averaged only 64% of beef prices since 1978 (Drabenstott and Duncan 1982). Retail poultry prices averaged only 41% of beef prices during the past two decades, but only 30% of beef prices during the past three years. Concurrent with these relative price declines, pork and poultry consumption have increased, contributing to beef industry concern.

Relative retail prices are consistent with total production costs per lb. liveweight for 1972-80 (Trapp 1982):

	Cents per lb. - 1972-80	
	Costs	Net Return
Beef	50.57	-3.97
Pork	42.60	-1.04
Chicken	21.60	2.12

Costs are for the feeding (fattening) stage for beef and for the entire production period for pork and chicken.

Returns were quite variable and averaged negative for beef and pork. Returns were consistent, relatively small and averaged positive for chicken. It is relatively easy to adjust output of chicken and costs are more completely under control of the integrated producer. Output and costs of production of total beef, not just fed beef are adjusted slowly.

Another thought expressed at the Beef Profit Conference was "the further we look back, the better we are able to see ahead." This and the quote on "maturity" seem appropriate leads for discussion of the future of the consumption side of the livestock industry. Extensive use of visual materials from the Western Livestock Marketing Information Project will simplify this discussion.

On Maturity of the Livestock Industry

The maturation and changes in the livestock and meat supply industries can perhaps be indicated by considering fed cattle marketings which increased from about 10 million head in 1955 to over 26 million in 1972 (Figure 1). They have fluctuated with the cattle cycle since then. We should expect that to continue in the future, if the industry is in fact mature.

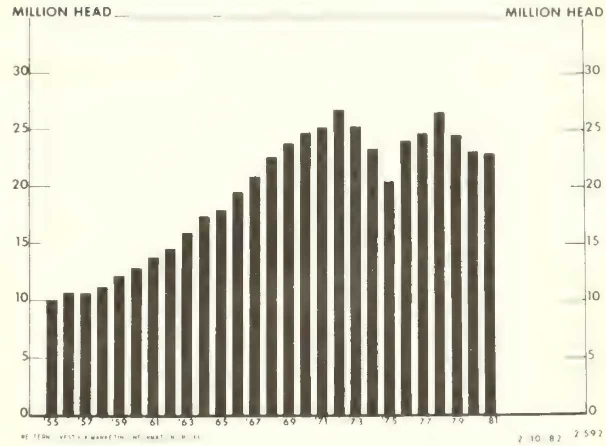

Figure 1. Fed cattle marketings (23 states), 1955 - 1981.

Commercial cattle slaughter is shown in Figure 2. It reflects increased cattle feeding from 1965 until 1972 and maturity in that industry since then. Slaughter lags behind the cattle numbers cycle slightly. Slaughter remained quite high through 1978 and has been much lower since then. Non-feed steer and heifer slaughter was reduced as feeding increased, and since reaching a low point in 1973 has been a "shock absorber" varying with cattle numbers and concentrate feed supply conditions. Slaughter of cull cows and bulls is closely related to the cattle numbers cycle.

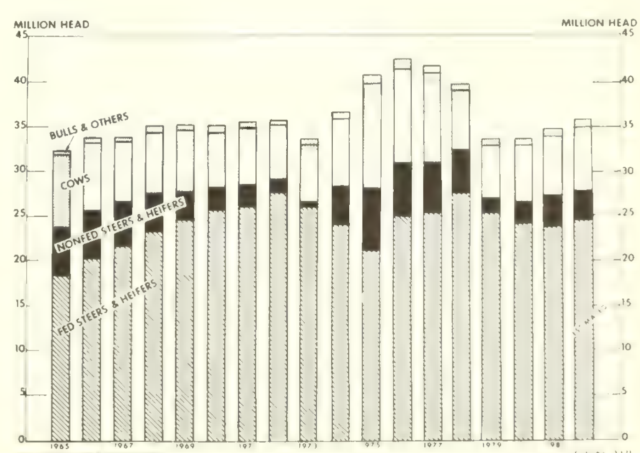

Figure 2. Commercial cattle slaughter, 1965 - 1982.

Production of red meats is shown in Figure 3, and per capita consumption of red meats poultry/and fish is shown in Figure 4. Changes in production and consumption will be seen more clearly on separate subsequent charts.

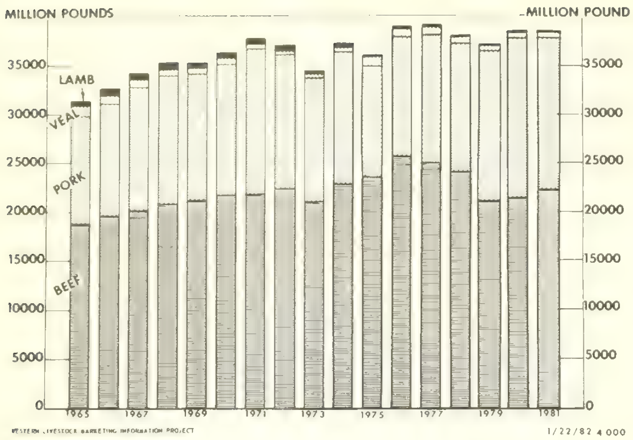

Figure 3. Production of red meat.

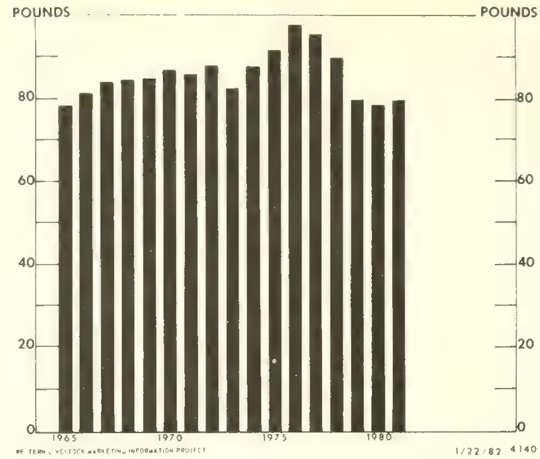

Figure 5. Beef consumption per person, 1965 - 1981 (retail weight).

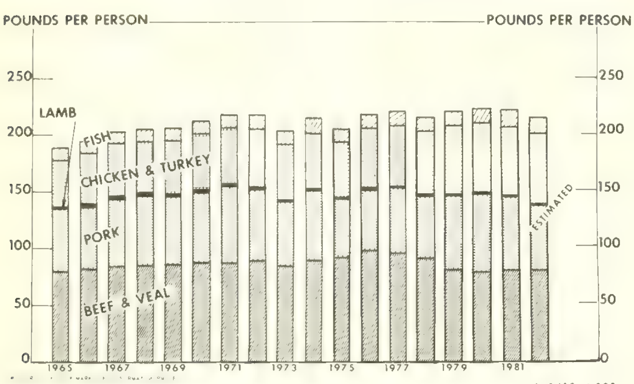

Figure 4. Consumption of meat, poultry, & fish, 1965 - 1982, retail weight equivalent.

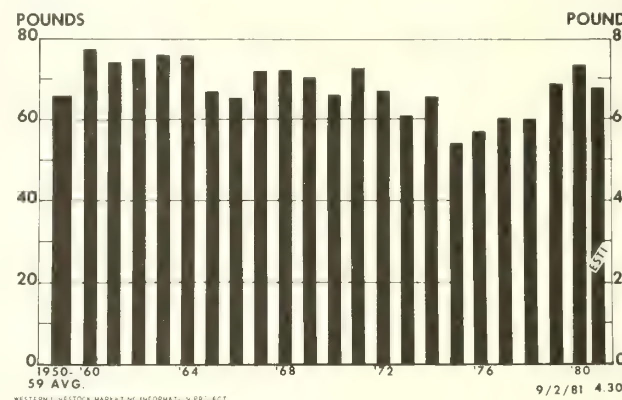

Figure 6. Pork consumption per person.

Beef

Beef consumption per capita is shown in Figure 5. An old and simple concept bears repetition. Whatever is produced will be consumed. Consumption of beef is consistent with the cattle cycle. Beef consumption declined from 47% to 37% of the total red meat and chicken between 1976 and 1980 (Ikerd 1982). Ikerd suggested that beef demand has shifted as market share shifted, with a downward shift in demand recently.

Pork

Pork consumption per capita is shown in Figure 6. Recently some concern has been expressed by beef producers about a resurgence of preference for and consumption of pork. If a short-term view is taken, say 1975 to present, their concern appears justified as the pork share of consumption increased from 27% in 1976 to 33% in 1980. If we look a little further back, the swine industry is also seen as "mature".

Poultry

Poultry consumption per person is shown in Figure 7. For 1950-54 consumption of chicken and turkeys averaged about 22 lb. and 6 lb. By 1965 consumption had increased to about 34 lb. of chicken and 8 lb. of turkey. It is now about 50 lb. of chicken and 10 lb. of turkey, with some suggestion of impending maturity of that industry. The poultry share increased from 27% to 30% between 1976 and 1980.

Implications

Recently there have been comments that the problems for the beef industry have stemmed from a decline in real expenditures for beef, per capita. That problem is not unique to beef, but is common to pork and poultry, as well, and is a result of rising total incomes, a "stomach capacity" limit, and an abundance of meat.

Pork and poultry cost less to produce than beef. They also cost less at the retail market. There is still a question, perhaps a divergence of opinion about consumer preferences for beef vis-a-vis pork and poultry. Beef has lost a significant amount of total meat market share, but much of that loss is tied to the cattle cycle and expanding hog cycle.

Market share gains of chicken have been persistent through two decades. The real problems seem to be the large supply of total meat depressing prices, not any real shift in preferences or demand for total meats, nor any very significant shift in demand for beef. The fact that beef had held most of its market share at much higher prices than for other meats is still encouraging.

Figure 7. Poultry consumption per person 1965 - 1981.

FEED GRAINS

When considering the production side, hay was mentioned as part of the forage supply, and an important consideration in the economics of range livestock areas. Obviously, hay is mostly utilized at the locations of production. Certainly there is little movement of hay for use by beef cattle or sheep.

Feed grains, mostly corn but also including grain sorghums, barley and oats, are used extensively for feeding beef cattle and to a limited extent in the breeding herd or range beef cattle stages. Unlike hay, feed grains also move in national and international markets. The future for feed grains is certainly relevant to the future of the range livestock industries. For the 1981-82 marketing year total use of feed grains excluding food, alcohol and seed is expected to be:

	Billion bushels
Corn	6.3
Sorghums	.7
Barley and oats	.8

Because of the pre-eminent position of corn it will be used as a proxy for all feed grains.

Corn supplies and utilization are shown in Figure 8. Production was quite low in 1970, 1974 and 1980. Feed use varies with production (inversely with prices) and is affected by the cattle and hog cycles. The most notable changes are in exports, which are shown more clearly in Figure 9. Exports have increased from about .5 billion bushels in 1970 to 2.4 billion bushels in 1980. In effect exports provided the outlet for increased feed production after 1972 as cattle feeding "matured".

A high level of exports seem necessary for agriculture and for other nations.

The natural gas pipeline from the Soviet Union to Eastern and Western Europe could increase Soviet gas exports three fold to Western Europe and by 50% to eastern Europe (Minard 1982). That could have favorable implications for agricultural exports.

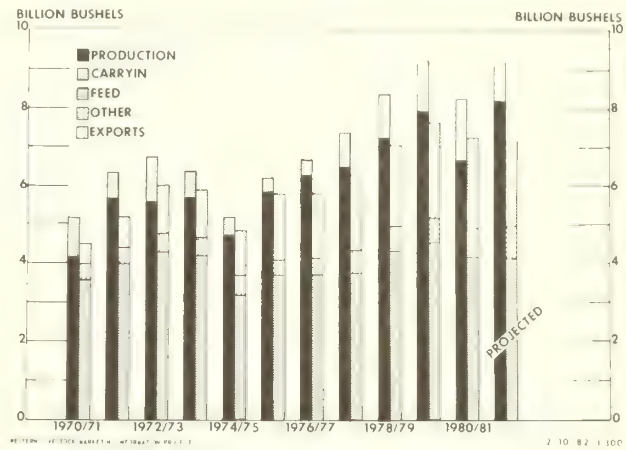

Figure 8. Corn supplies & utilization, 1970 - 1981.

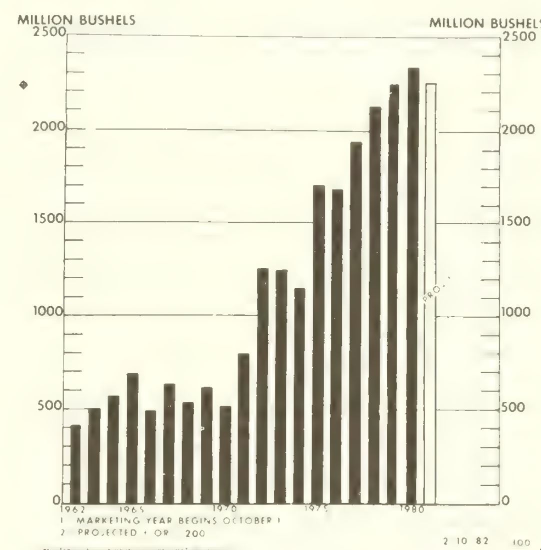

Figure 9. U.S. corn exports, 1962 - 1981.

ENERGY, RANGELANDS AND AGRICULTURE

One finds varying and frequently changing interpretations of the current reality and extent of "energy crisis." Some people, thinking twenty years ahead, still see energy scarcity as a matter of real concern. Coal and petroleum are stock resources which resulted originally from photosynthesis processes and were ultimately converted to the present form by other processes. Petroleum exporting countries are exhausting a stock resource which often represents a major part of their known resources. It seems quite logical for them to restrict the volume of petroleum output, extend

the time period over which the output will be available, and extract a high price as output is being produced.

The production of crops represent ways of capturing solar energy and harvesting it in a storable, transportable form. Production of range forage represents solar energy which is captured only to the extent that the forage is utilized efficiently. The present price situation may suggest a short-term and short-sighted solution of reduction of grazing and of livestock production. The longer-term and better solution I believe, should involve an increased reliance on and more efficient use of range forages to make an increased supply of feed grains available for export. That, in turn, provides a means of acquiring supplies of stock resources, energy, and other goods from other countries.

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NOTE: APPENDIX TABLES FOLLOW.

In: Wagstaff, Fred J., compiler. Proceedings--range economics symposium and workshop; 1982 August 31-September 2; Salt Lake City, UT. Gen. Tech. Rep. INT-149. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983.

Appendix Table 1. Cattle inventory numbers in the western and great plains states, 1972-81 averages January 1. (1,000 head)

State and Region	1/ Cows		2/ Replacements		3/ Steers and Heifers	4/ Calves	Bulls	All Cattle & Calves	Calves born	Cattle fattening	
	Beef	Milk	Beef	Dairy						on feed	5/ Marketed
Pacific											
California	973	828	225	316	378	1,105	78	4,801	1,605	898	1,682
Oregon	650	93	111	32	129	401	42	1,536	672	78	148
Washington	381	187	85	73	163	311	27	1,395	519	168	369
Sub-total	2,004	1,108	421	421	670	1,817	147	7,732	2,796	1,144	2,199
Rocky Mountain											
Arizona	317	65	46	15	46	257	26	1,208	313	436	749
Colorado	986	74	187	30	274	759	60	3,316	946	946	2,138
Idaho	642	148	112	74	150	542	41	1,935	752	226	424
Montana	1,562	29	279	10	168	747	90	2,982	1,591	97	144
Nevada	322	14	51	7	30	156	17	627	280	30	5/
New Mexico	637	34	105	10	93	448	40	1,566	591	199	335
Utah	335	77	55	40	55	224	18	861	366	57	5/
Wyoming	716	13	138	3	104	438	44	1,501	692	45	5/
Sub-total	5,517	454	973	189	920	3,571	336	13,996	5,531	2,036	3,790
Plains											
Kansas	1,834	140	266	47	1,125	1,734	94	6,470	1,816	1,230	2,834
Nebraska	2,103	143	310	38	689	1,762	114	6,720	2,069	1,561	3,662
North Dakota	1,063	112	157	25	176	623	55	2,251	1,163	40	74
Oklahoma	2,324	120	362	36	801	1,712	122	5,777	2,183	300	648
South Dakota	1,731	165	245	45	261	1,389	90	4,287	1,853	361	572
Texas	6,169	331	1,009	100	968	3,957	422	14,836	5,614	1,880	4,153
Sub-total	15,224	1,011	2,349	291	4,020	11,177	897	40,341	14,698	5,372	11,943
17 State Total	22,745	2,573	3,743	901	5,610	16,565	1,380	62,069	23,025	8,552	17,932
U.S. Total	40,535	11,132	6,874	3,990	10,881	31,456	2,596	120,290	46,735	12,826	24,242

Sources: See Table 1.

1/ Cows that have calved
2/ Heifers or steers over 500 lbs.
3/ Steers and heifers over 500 lbs not on feed.
4/ Calves under 500 lbs.
5/ Average marketed 1972-1980. Information not available for all states.

Appendix Table 2. Production, value of production, prices and AUM equivalents of calves, western and great plains states, 1972-1980

State and	Production		Average Prices (per cwt)		AUM	Per AUM Equivalen	
Region	Amount	Value	Cattle	Calves	Equivalent	Production	Valu
Pacific	(million lb)	($ million)	(dollars)	(dollars)	(thousands)	(lb)	(dolla
California	1,797	793	44.67	47.07	57,612	31.19	13.7
Oregon	498	212	41.18	46.30	18,432	27.02	11.5
Washington	423	190	43.03	43.35	16,740	25.27	11.3
Sub-total	2,718	1,195			92,784	29.29	12.8
Rocky Mountain							
Arizona	620	286	45.43	50.87	14,496	42.77	19.7
Colorado	1,700	798	46.92	54.78	39,792	42.72	20.0
Idaho	672	312	44.87	52.60	23,220	28.94	13.4
Montana	981	440	42.49	53.46	35,784	27.41	12.3
Nevada	189	84	42.27	50.28	7,524	25.12	11.1
New Mexico	620	291	46.44	50.29	18,792	32.99	15.4
Utah	254	107	40.63	50.50	10,332	24.58	10.3
Wyoming	515	236	45.00	55.82	18,012	28.59	13.1
Sub-total	5,551	2,554			167,952	33.05	15.2
Plains							
Kansas	2,689	1,201	44.50	51.66	77,640	34.63	15.4
Nebraska	2,479	1,263	45.10	52.52	80,640	30.74	15.6
North Dakota	839	366	42.88	53.08	27,012	31.06	13.5
Oklahoma	2,109	929	43.51	51.62	69,324	30.42	13.4
South Dakota	1,724	785	45.07	54.70	51,444	33.51	15.2
Texas	5,162	2,247	43.38	50.06	178,032	28.99	12.6
Sub-total	15,002	6,791			484,092	30.99	14.0
17-States	23,271	10,540			744,828	31.24	14.1
U.S.	40,754	17,645			1,443,480	28.23	12.2

Sources: See Table 1.

Appendix Table 3. Sheep, lambs and wool western and great plains states - 1972-81 average inventories, 1972-80 average production and value (thousands of all units, numbers, lb., or dollars).

State and	Total	Lambs and sheep	All sheep	Production		Value of Production		
Region	stock sheep	on feed	and lambs	Lambs and sheep	Wool	Lambs and sheep	Wool	Tota
Pacific	(number)	(number)	(number)	(lb)	(lb)	(dollars)	(dollars)	(dollar
California	961	165	1,126	67,721	10,642	31,363	7,164	38,527
Oregon	368	95	463	25,976	3,440	10,598	2,333	12,931
Washington	84	10	94	5,451	871	2,322	544	2,866
Sub-total	1,413	270	1,683	99,148	14,953	44,283	10,041	54,324
Rocky Mountain								
Arizona	362	90	452	20,113	2,957	7,763	1,576	9,339
Colorado	555	405	960	70,788	9,233	33,455	6,062	39,517
Idaho	537	36	573	47,054	5,777	19,955	3,759	23,714
Montana	629	66	695	31,146	5,859	11,637	4,367	16,004
Nevada	135	15	150	8,338	1,283	3,429	842	4,271
New Mexico	594	40	634	18,330	5,374	8,073	3,661	11,734
Utah	655	40	695	36,070	6,566	15,051	4,124	19,175
Wyoming	1,166	146	1,312	50,083	12,087	19,696	8,334	28,030
Sub-total	4,633	838	5,471	281,922	49,136	119,059	32,725	151,784
Plains								
Kansas	168	67	235	14,544	1,924	6,403	1,107	7,510
Nebraska	150	111	261	14,420	1,828	5,869	1,035	6,904
North Dakota	219	69	288	15,643	2,174	6,012	1,358	7,370
Oklahoma	74	20	94	5,083	652	2,135	360	2,495
South Dakota	775	74	849	65,194	7,670	27,892	5,235	33,127
Texas	2,492	235	2,727	124,311	22,462	49,418	17,104	66,522
Sub-total	3,878	576	4,454	239,195	36,710	97,729	26,199	123,928
17 States	9,924	1,684	11,608	620,265	100,799	261,071	68,965	330,036
U.S.	12,321	2,057	14,378	784,217	120,802	330,542	79,797	410,339

Sources: See Table 1.

"Sheep, Lambs and Goats: Final Estimates for 1976-79." Economics and Statistics Service. Statistical Bulletin 653. U.S. Department of Agriculture.

"Sheep and Goats." Crop Reporting Board, Statistical Reporting Service. U.S.D.A., January, 1981 and 1982

Appendix Table 4. AUM's required for sheep and lambs and 1972-80 average production and value of production per AUM equivalent in the western and great plains states (lb. and dollars)

State and Region	AUM's	Production per AUM: Lambs and sheep	Production per AUM: Wool	Value of Production per AUM: Lambs and sheep	Value of Production per AUM: Wool	Value of Production per AUM: Total
	(thousands)	(lb)	(lb)	(dollars)	(dollars)	(dollars)
Pacific						
California	2,388	28.36	4.46	13.13	3.00	16.13
Oregon	930	27.93	3.70	11.40	2.51	13.91
Washington	208	26.21	4.19	11.16	2.62	13.78
Sub-total	3,526	28.12	4.24	12.56	2.85	15.41
Rocky Mountain						
Arizona	914	22.00	3.23	8.49	1.73	10.22
Colorado	1,535	46.12	6.01	21.79	3.95	25.74
Idaho	1,307	36.00	4.42	15.27	2.88	18.15
Montana	1,543	20.18	3.80	7.54	2.83	10.37
Nevada	332	25.11	3.86	10.33	2.54	12.87
New Mexico	1,446	12.68	3.72	5.58	2.53	8.11
Utah	1,592	22.66	4.12	9.45	2.59	12.04
Wyoming	2,871	17.44	4.21	6.86	2.90	9.76
Sub-total	11,540	24.43	4.26	10.32	2.84	13.16
Plains						
Kansas	436	33.36	4.41	14.69	2.54	17.23
Nebraska	416	34.66	4.39	14.11	2.49	16.60
North Dakota	560	27.93	3.88	10.74	2.42	13.16
Oklahoma	188	27.04	3.47	11.36	1.91	13.27
South Dakota	1,897	34.37	4.04	14.70	2.76	17.46
Texas	6,099	20.38	3.68	8.10	2.80	10.90
Sub-total	9,596	24.93	3.83	10.18	2.73	12.91
17 States	24,662	25.15	4.09	10.58	2.80	13.38
U.S.	30,599	25.63	3.95	10.80	2.61	13.41

Appendix Table 5. Relative importance of livestock and hay production activities in the farm sector, various states and regions, 1979.

Region and Production Activity	Value Added ($ Millions): Livestock	Hay	Other	Total	Percent of Total: Livestock	Hay	Other
Pacific							
California	547.544	420.324	5,861.789	6,829.657	8.0	6.2	85.8
Oregon	227.660	91.590	505.411	824.665	27.6	11.1	61.3
Washington	146.033	112.950	1,171.762	1,430.745	10.2	7.9	81.9
Sub-total	921.237	624.868	7,538.962	9,085.067	10.1	6.9	83.0
Rocky Mountain							
Arizona	151.522	79.969	510.494	741.985	20.4	10.8	68.8
Colorado	491.913	103.528	594.989	1,190.430	41.3	8.7	50.0
Idaho	291.880	180.969	728.533	1,201.382	24.3	15.1	60.6
Montana	496.949	212.229	434.373	1,143.551	43.4	18.6	38.0
Nevada	77.561	63.044	23.463	164.068	47.2	38.4	14.4
New Mexico	249.689	50.120	149.408	449.217	55.6	11.2	33.2
Utah	95.370	76.490	123.858	295.718	32.1	25.8	42.1
Wyoming	279.593	86.054	87.949	453.596	61.6	19.0	19.4
Sub-total	2,134.477	852.403	2,653.067	5,639.947	37.8	15.1	47.1
Plains							
Kansas	798.284	240.598	2,492.764	3,531.646	22.6	6.8	70.6
Nebraska	917.249	291.129	2,279.041	3,487.419	26.3	8.4	65.3
North Dakota	406.456	168.548	1,484.999	2,060.003	19.7	8.2	72.1
Oklahoma	851.782	163.387	1,082.460	2,097.629	40.6	7.8	51.6
South Dakota	837.834	212.735	1,065.268	2,115.837	39.6	10.0	50.4
Texas	1,652.392	200.660	3,326.719	5,179.771	32.0	3.9	64.1
Sub-total	5,463.997	1,277.057	11,731.251	18,472.305	29.6	6.9	63.5
3 Regions Total	8,519.711	2,754.328	21,923.280	33,197.319	25.7	8.3	66.0

Sources: See Table 3.

RANGELAND AS A COLLECTIVE CAPITAL GOOD

Richard E. Howitt

ABSTRACT: Collective goods are defined as having nonconvex transaction costs. In this case property rights alone do not ensure an efficient supply of several range outputs, wildlife, recreation, and watershed catchment. Recognition of the stock nature of rangeland requires a capital theory model to analyze the incentives for efficient rangeland production under alternative institutions.

INTRODUCTION

The agencies administering public rangelands are currently on the political defensive against advocates of a sweeping change towards private ownership. The sagebrush revolutionaries infer that the logic of economic efficiency is behind their proposition (Libecap 1981). This paper takes the viewpoint of a newcomer to this branch of resource economics in using a theoretical approach to address the following questions. First, are there inherent properties of some of the multiple uses of public rangeland that make them collective goods? That is, goods that will not be supplied by a private market. Second, what is the theoretical basis for inefficiencies imposed on the livestock sector by publicly administered rangelands? What system of property rights would reduce these inefficiencies? Third, given the trends of increasing demands for nonlivestock range uses, will the ratio of the costs of government failure to market failure increase or decrease over time?

While there is a long history of research into these questions, and, I am glad to say, the results will be intuitive to all of you, I think it important to establish the theoretical basis for claims of economic efficiency. Since the grazing industry depends on a flow of productivity from the range but many other uses; wildlife, recreation, and watershed values depend on the stock of biomass on the range, recognition of the capital nature of the problem is needed. Stevens and Godfrey (1972) state "The physical productivity of investments and the responsiveness of resource flows to prior use rates are particularly important . . . The actual realization of increased use rates, however, depends upon the institutional and incentive frameworks of the decision maker."

Stevens and Godfrey suggested an approach to analyzing their dynamic model, but concentrated on empirical results for a static version of the model. This paper makes a theoretical attempt to obtain the dynamic qualitative properties of the economic incentives under the alternative institutions of private ownership and public regulation. The range management problem is essentially one of optimum capital use and accumulation. However, I am not aware of a capital theory approach to range management other than Stevens and Godfrey (1972) and Burt (1971). Given the subsequent comments in the literature to Burt's article [Bromley (1972), Martin (1972)] it is clearly dangerous ground and I must trust that the theory is more pratical and the data more available than ten years ago.

COLLECTIVELY SUPPLIED GOODS

Arrow (1969) argues that externalities can be eliminated by a sufficiently comprehensive set of markets, while at the other extreme Heller and Starrett (1976) point out that in a pure barter economy all effects are externalities under the conventional definition of interdependent production (or utility) functions. Clearly the conventional definition of externalities is not useful, and Coase's (1960) seminal article by its assumption of zero transaction costs explains the reason. Externalities occur when markets are absent, and markets are absent when transaction costs are prohibitively high. By transaction costs I mean the costs of defining the property rights, negotiating a trade, transferring the property right and enforcing the trade.

It is a short step from this definition of externalities to the logic that since it is unprofitable to establish private markets, efforts to internalize the externalities through social regulation are inherently inefficient and can only be justified on distributional grounds. The property rights equivalent of the Coase theorem is that given a sufficiently rich set of property rights all economically efficient goods will be supplied. Two critical implicit assumptions underlie this argument. First, that the appropriate transaction cost technology is convex and thus transactions are private goods to be supplied like any other. Second, that the public transaction costs are similar to private transaction costs. That is, there are no economies of scale in transacting.

Foley (1970) has shown that efficient equilibria exist when the transactions technology is convex, and Starr (1969) shows that quasi-equilibria can be achieved if transaction costs are small relative to the market. Given my definition of transaction costs which requires the setting up of market institutions, it is clear that the fixed costs involved violate the convexity requirement. Furthermore, since the transaction costs determine the existence of markets, they cannot be

Richard E. Howitt is an Associate Professor in the Department of Agricultural Economics at the University of California-Davis, Davis, Calif.

characterized as relatively small. One can therefore conclude that if the market transaction costs are significant and nonconvex, a full set of property rights is a necessary but not sufficient condition for efficient market allocation. If, for instance, the nonconvex transaction technology was only caused by institutional set up costs, then externality inefficiencies would exist until publicly supplied institutions moved the market to the convex part of the transactions cost function. A classical example of this phenomenon is that of colonial traders following the collectively supplied gunboats.

Do the nonlivestock range uses of recreation, wildlife, and watershed with their attendant option demands have these properties that ensure that they are not supplied by a private market system, but can be efficiently supplied as collective goods? Heller and Starrett (1976) show that the nonconvexities can be caused by violation of either additivity or divisibility in the production set. Recreation on large areas of rangeland is clearly a nondivisible good in its production, most particularly when the attributes sought by the recreation are those of space and solitude. Attempts to divide this commodity would totally change the nature of the good.

Wildlife on the range has many private goods characteristics when hunting areas are delineable and charges can be levied per unit of access or kill. There are other wildlife constraints and values on the range that are not divisible into market units, many of these uses are comparatively recent and represent demands for the existence of habitat for raptors or wild horses and burros, etc. (Johnston and Yost 1979). The demand for these habitats has the property of an option demand in that actual contact with these wild species is rare. These option demands are indivisible and largely nonexchangeable, thus violating convexity properties both in production and consumption. Brookshire, Eubanks and Randall (1979) have developed methods to measure option demands.

The value of public rangelands as water catchments is being increasingly recognized as the scarcity of western water resources increases, while increased runoff is often a joint product of rangeland pasture improvements, production of usable water from an area is subject to indivisibilities and problems of defining the boundaries of catchment areas especially when all or part of the flows are subsurface.

Mineral exploration and development are competing uses with livestock and other collective outputs from rangeland, but the nature of the technical externalities involved requires publicly constrained private development. The optimal level of exploration and development can be delivered by considering this activity as private production that jointly produces negative externalities on all the other rangeland uses.

Given the transaction problems caused by the divisibility, addivitity, and boundary delineation properties of many outputs of rangeland, a full set of property rights is not a sufficient condition for the private market supply of all efficient goods. This conclusion is based solely on considerations of technical efficiency in the economic system. Equity considerations are likely to further reinforce the qualitative conclusions.

It was argued earlier that property right institutions are discrete alternatives, with significant set up costs. Thus the optimum choice of institutions reduces to a benefit/cost comparison of reasonable alternatives. For contrast, two radical choices are considered. The system of central agency management prevalent over many Western ranges, versus the complete private ownership of the ranges by livestock producers advocated by some academicians, producers and politicians. The relative desirability of either institution depends on the ratio of the costs of "government failure" and "market failure" that will occur in each of these alternatives.

To return to the problem posed by Stevens and Godfrey (1972) a highly simplified dynamic model of the economics of multiple use rangeland is developed to examine the incentives under the institutional alternatives.

A SIMPLE DYNAMIC RANGELAND MODEL

A highly aggregated and simplified model of multiple use rangeland is specified with three state or stock variables and three control or decision variables. A minimal representation can be acheived by Y_{1t} range biomass in time t, Y_{2t} an index of the wildlife population and Y_{3t} the capital stock of improvements to the range grazing. The three control variables are U_{1t}, the livestock stocking rate in time t; U_{2t}, investment in range improvements; and U_{3t}, the intensity of hunting or control of the wildlife. It is assumed that the representative wildlife are herbivores and compete for range biomass with the livestock, but do not prey directly on the livestock.

The model objective function is divided into measure of private net revenues to livestock ranchers, $f_1(t, U_{1t}, U_{2t})$. Profit maximizing ranchers will therefore optimize the present value of the stream of discounted net revenues over a given horizon

$$(1)\ \text{Max} \int_{t_o}^{T} e^{-rt} f_1(t, U_{1t}, U_{2t})\, dt.$$

$$\frac{\partial f_1(\cdot)}{\partial U_1} > 0, \qquad \frac{\partial f_1(\cdot)}{\partial U_2} < 0$$

In this paper, the model will be specified in continuous time for simplicity of notation and time derivatives.

The public agency objective function is specified to maximize the present value of a monetary measure of collective utility from Y_{1t} the stock of range biomass when valued for recreational and aesthetic reasons, Y_{2t} the stock level of wildlife, and U_{3t} the intensity of hunting in any period. The collective goods objective of the managing agency is:

$$(2)\ \text{Max} \int_{t_o}^{T} e^{-rt} f_2(t, Y_{1t}, Y_{2t}, U_{3t})\, dt$$

$$\frac{\partial f_2(\cdot)}{\partial Y_1} > 0, \quad \frac{\partial f_2(\cdot)}{\partial Y_2} > 0, \quad \frac{\partial f_2(\cdot)}{\partial U_3} > 0$$

The time rate of change of the three state variables is described by three differential equations similar to the difference equations specified by Stevens and Godfrey. The dynamics are represented by:

$$\dot{Y}_1 = g_1(Y_{1t}, Y_{2t}, Y_{3t}, U_{1t}) \quad \frac{\partial g_1(\cdot)}{\partial Y_1} > 0,$$

$$\frac{\partial g_1(\cdot)}{\partial Y_2} < 0, \quad \frac{\partial g_1(\cdot)}{\partial Y_3} > 0, \quad \frac{\partial g_1(\cdot)}{\partial U_1} < 0$$

$$(3)\ \dot{Y}_2 = g_2(Y_{1t}, Y_{2t}, U_{1t}, U_{3t}) \quad \frac{\partial g_2(\cdot)}{\partial Y_1} > 0,$$

$$\frac{\partial g_2(\cdot)}{\partial Y_2} < 0, \quad \frac{\partial g_2(\cdot)}{\partial U_1} < 0, \quad \frac{\partial g_2(\cdot)}{\partial U_3} < 0$$

$$\dot{Y}_3 = g_3(Y_{3t} \cdot U_{2t}) \quad \frac{\partial g_3(\cdot)}{\partial Y_3} < 0, \quad \frac{\partial g_3(\cdot)}{\partial U_2} > 0$$

[Note, $\dot{Y}$ is defined as dy/dt in general.]

Collapsing the two objective functions into the vector function $F(\cdot)$ and the three equations of motion into $G(\cdot)$. The current value Hamiltonian is defined as:

$$(4)\ H_t = F(t, \underline{Y}\ \underline{U}) + e^{rt}\lambda_t\, G(t, \underline{Y}\ \underline{U})$$

where λ_t is a 3x1 vector of costate variables associated with the state variables. The costate variables can be shown to be equal to the marginal value over the whole horizon of the state variables at any given time. The optimal control problem of maximizing $F(t, \underline{Y}_t, \underline{U}_t)$ over the period t_o - T subject to the initial conditions $\underline{Y}_{to}$ and the biological relationships represented by $G(t, \underline{Y}_t\ \underline{U}_t)$ is achieved by maximizing the Hamiltonian function at all time periods. The Pontryagin Maximum principle proves that the optimum path of actions $\underline{U}^*_t$ has to satisfy the following necessary conditions (Arrow and Kurz 1970; Kamien and Swartz 1981).

$$(5)\ \frac{\partial H_t}{\partial \lambda_t} = \dot{Y} \qquad \text{for all t} \qquad \text{Condition I}$$

$$(6)\ \frac{\partial H_t}{\partial U_t} = 0 \qquad \text{for all t} \qquad \text{Condition II}$$

$$(7)\ -\frac{\partial H_t}{\partial Y_t} = \dot{\lambda} \qquad \text{for all t} \qquad \text{Condition III}$$

If the costate is expressed in terms of current values it is defined as $\gamma_t \equiv e^{rt}\lambda_t$ and condition (III) becomes

$$(8)\ -\frac{\partial H_t}{\partial Y_t} = \dot{\gamma} - r\gamma_t$$

A brief interpretation of the Pontryagin conditions is that (5) requires that the time change of states must satisfy the biological relationships. Equation (6) says that since the biological constraints are embedded in the Hamiltonian H_t, a optimum solution requires an interior optimum wit respect to the controls. Condition (8) determine the time rate of change of the marginal value of the stocks of rangeland capital. More specific interpretations are given in later sections.

This simplified model in continuous time may appear impractical but could be empirically implemented quite easily. The conversion to discrete time periods necessary for empirical estimates is straightforward and the first order simultaneous difference equations used in Stevens and Godfrey would be most appropriate for the growth functions $G(\cdot)$. The private value functio of grazing and range improvements $f_1(\cdot)$ can be estimated from an appropriate range management study. The empirical function $f_2(\cdot)$ will be hard to accurately estimate, but work is progressing i this area (Brookshire and others 1979).
If value functions are unavailable, the maximum and minimum bounds can be specified by inequality constraints. Algorithms to solve this class of control problems are available even under significant increases in the vector dimensions which would allow the interaction of several multiple uses of rangelands and a alternative control policies.

THE COSTS OF "GOVERNMENT FAILURE"

Government failure, as opposed to market failure, occurs when a government administered economic process fails to produce the socially optimal output or investment. The qualitative properties of the costs of regulated livestock production ca be deduced by comparing the necessary conditions for optimum private production from rangeland wit regulated production conditions.

Under private range management [equation (5)]--th biological dynamics obviously have to hold. The two control variables facing the rancher are current stocking rates and range improvement investments to make in a given year. Condition I becomes:

$$(9)\ \frac{\partial f_1(\cdot)}{\partial U^*_{1t}} + \gamma^*_{1t} \frac{\partial g_1(\cdot)}{\partial U^*_{1t}} + \gamma^*_{2t} \frac{\partial g_2(\cdot)}{\partial U^*_{1t}} = 0$$

$$(10)\ \frac{\partial f_1(\cdot)}{\partial U_{2t}} + \gamma^*_{3t} \frac{\partial g_3(\cdot)}{\partial U_{2t}} = 0$$

Equation (9) says that the rancher equates the immediate monetary benefits from increased stocking rates to the marginal value of the range biomass in the future, times the marginal physica effect of increased stocking on the biomass. Tha is, the marginal short-run benefits are equated t the marginal long-run opportunity costs. Note that γ^*_{1t} is not the same as γ_{1t} in equation (8), as under the institution of private rancher ownership $f_2(\cdot)$ does not enter the objective function. Given this assumption γ^*_{2t} will be zero for the rancher. Equation (10) states that at every instant the cost of investment in improvements must be equated to the marginal capital value of the improvements to the rancher.

Under an administered grazing system, the rancher is unable to rely on the capital value of future grazing. On a strictly annual permit basis, γ_1^* and γ_3^* would be zero, giving rise to the familiar problem of zero investment and overgrazing under open access.

A public administrator could plan to calculate what the optimum grazing level would be under equation (9) and set the permits at this level. Unfortunately, the problem is not static. While the administrator knows the immediate grazing returns to the rancher $\frac{\partial f_1(\cdot)}{\partial U_1}$ and the biological effects $\frac{\partial g_1(\cdot)}{\partial U_1}$, knowledge of γ_{1t}^* is much harder.

Equation (8) describes how γ_t^* the current marginal value of range biomass changes over time, (8) can be rewritten as:

$$(11)\quad \dot{\gamma}_1^* = r\,\gamma_{1t}^* - \gamma_{1t}\frac{\partial g_1(\cdot)}{\partial Y_1} - \gamma_{2t}\frac{\partial g_2(\cdot)}{\partial Y_1}$$

That is, in order to hold the capital asset of rangeland, the capital appreciation of rangeland must be equal to the opportunity cost of capital in the range less the imputed value of the biological growth that is made on the range in any given time period. Evidently, a range administrator would have to have accurate expectations of not only the range, but also the cattle cycle, the ranchers' opportunity cost of capital and the feed condition of the contiguous ranch property to closely approximate the economically optimum stocking rate. In short, the administrator would have to be a rancher.

Assuming, perhaps unfairly, that the administered stocking rate is held constant, a risk averse solution would be to maintain the stocking rate at the level that is justified by the lower third of the cattle cycle prices and below average range conditions. Given these constraints, ranchers would not be able to capture profits from upturns in the cattle cycle or range conditions and the costate on range biomass γ_{1t}^* would be zero. One cost component would be $\gamma_{1t}^*\frac{\partial g_1(\cdot)}{\partial U_{1t}^*} - \frac{\partial f_1(\cdot)}{\partial \bar{U}_{1t}}$ integrated over a specified time period, where $\bar{U}_{1t}$ the administered stocking rate may be above or below the optimum U_1^* depending on the cattle cycle and range conditions. The second cost of government failure is the social value of optimal increased production from rangeland improvements, equation (10) shows this to be $\gamma_{3t}^*\frac{\partial g_3(\cdot)}{\partial U_{2t}}$ integrated over the same period, for a single year an extreme case of government failure could cost

$$(12)\quad \int_0^1 \gamma_{1t}^*\frac{\partial g_1(\cdot)}{\partial U_{1t}^*} - \frac{\partial f_1(\cdot)}{\partial \bar{U}_{1t}} + \gamma_{3t}^*\frac{\partial g_3(\cdot)}{\partial U_{2t}}\,dt.$$

In practice the existence of ten-year leases, and some range inprovements would reduce this cost.

PRIVATE MARKET FAILURE COSTS

The costs to society of complete private ownership of the range are defined by deriving the conditions for the socially optimal multiple use management, and removing those collective goods that would not be supplied under a full set of private property rights. Given the Hamiltonian defined in equation (4) the necessary conditions are: Condition I unchanged, Condition II [equation (6)] is optimized with respect to the two control variables--stocking rate U_1 and hunting intensity U_3:

$$(13)\quad \frac{\partial f_1(\cdot)}{\partial U_{1t}} + \gamma_{1t}\frac{\partial g_1(\cdot)}{\partial U_{1t}} + \gamma_{2t}\frac{\partial g_2(\cdot)}{\partial U_{1t}} = 0$$

$$(14)\quad \frac{\partial f_2(\cdot)}{\partial U_{3t}} + \gamma_{2t}\frac{\partial g_2(\cdot)}{\partial U_{3t}} = 0$$

Equation (13) differs from the rancher's optimum (9) in two ways. First γ_{1t} will be larger than γ_{1t}^*. Since γ is the partial derivative of the objective function with respect to the state, additional value functions in the objective function related to Y_1 imply that $\gamma_{1t} > \gamma_{1t}^*$. In addition, the socially optimal solution values wildlife, so γ_2 is positive. The combined effect is to make the long-run costs of stocking rates higher. If U_1 is in the normal part of the production function, a reduction in private stocking rates will be needed to achieve the social economic optimum. The cost of private market failure over a unit time is the difference between the private value at the optimal private grazing level and the social value at the lower optimal level, plus the value gained from hunting access, which is assumed a fully collective good.

$$(15)\quad \int_0^1 \gamma_{1t}\frac{\partial g_1(\cdot)}{\partial U_{1t}} - \gamma_{1t}^*\frac{\partial g_1(\cdot)}{\partial U_{1t}^*} + \gamma_{2t}\frac{\partial g_2(\cdot)}{\partial U_{1t}}\,dt.$$

In the absence of the imputed value of wildlife through γ_{2t}, the increase in γ_1 over γ_1^* would more than compensate for the reduction in the marginal biological effect. This is because the social value function $f_2(\cdot)$ contains the range biomass stock as a direct argument. That is $\frac{\partial f_2(\cdot)}{\partial Y_1} > 0$.

It has already been argued that the choice of institutions is a discrete benefit/cost decision. Clearly, the costs of alternative institutions should be considered. However, given the theoretical basis of this paper, empirical measurement of the costs and benefits is beyond its scope. One additional qualitative conclusion can be drawn concerning the likelihood that demand developments favor the public or private property institutions for rangeland.

As a starting point, consider the costs of private and public institutions to be the same, and current costs of market and government failure on rangeland to be equal. Dramatic changes in the biological functional relationships through new technology or the profitability of ranching seem unlikely, therefore, changes in the cost of

private ownership (15) and public regulation (12) will occur through changes in the costates, (γ_t).

Condition III defines how the costate variables must change over time along the optimum path. The dynamic path of the three costates (or capital values) is:

$$(16)\quad \dot{\gamma}_1^* = r\,\gamma_{1t}^* - \gamma_{1t}\,\frac{\partial g_1(\cdot)}{dY_{1t}}$$

Smith and Martin (1972) find that nonmonetary outputs of ranch ownership are significant factors in explaining ranch sale prices in Arizona, but from a theoretical efficiency viewpoint the change in the private market costate for range biomass is shown by (16) to be proportional to the ranchers opportunity cost of capital.

The social rangeland biomass costate change is:

$$(17)\quad \dot{\gamma}_1 = r\,\gamma_{1t} - \frac{\partial f_1(\cdot)}{\partial Y_1} - \gamma_{1t}\,\frac{\partial g_1(\cdot)}{\partial Y_1} - \gamma_{2t}\,\frac{\partial g_2(\cdot)}{\partial Y_1}$$

and the wildlife costate is:

$$(18)\quad \dot{\gamma}_2 = r\,\gamma_{2t} - \frac{\partial f_2(\cdot)}{\partial Y_2} - \gamma_1\,\frac{\partial g_1(\cdot)}{\partial Y_2} - \gamma_2\,\frac{\partial g_2(\cdot)}{\partial Y_2}$$

Both these relationships are equilibrium path conditions which state that to be indifferent to holding capital in rangeland, the rangeland price must be such that the captial gains $(\dot{\gamma})$ must be equal to difference between the opportunity cost of holding rangeland $(r\gamma)$ and the direct benefits $\frac{\partial f(\cdot)}{\partial Y}$ plus the value of productivity gains $\gamma\,\frac{\partial g(\cdot)}{\partial Y}$.

If the collective good demands that underly the $f_2(\cdot)$ function shift out over time due to population and income pressures (Clawson 1967), the costate values γ_2 and $\frac{\partial f_2(\cdot)}{\partial Y_2}$ will also increase. To return to the equilibrium path, $\dot{\gamma}_1$ and $\dot{\gamma}_2$ will correspondingly increase.

Given the relatively static expected profitability of range livestock operations, the faster time rates of change of the collective capital values of rangeland means that the costs of private market failure will increase relative to collective market failure over the forseeable future.

CONCLUSION

This paper has argued on the grounds of theoretical economic efficiency that several rangeland outputs have collective goods characteristics. This implies that a full set of private property rights is a necessary but not sufficient condition for their efficient production. Because the private and collective rangeland outputs have both stock and flow properties, market distortions occur in the differences between capital values.

A simplified capital model of multi-output range production was specified and the necessary conditions under two polar cases of private and public institutions are derived to show the qualitative properties of the costs of market and government failure. Obviously, there are ranges in which either cost could empirically dominate and indicate an optimum private or public set of property rights. An empirical test of the model seems feasible.

However, the qualitative properties of the changes in capital value over time will tend to increase the costs (to society) of private ownership and trends in this institutional direction should be approached with caution. A more desirable alternative similar to proposals by Gardner (1963) and others is for an institution of limited private grazing rights that contain sufficient capital incentives for investment in improvements and efficient cyclical stocking. Solution of an empirical capital model would allow calculation of the different levels of market distortion under alternative opportunity costs and marginal capital values.

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RANGE ECONOMICS IN THE BUREAU OF LAND MANAGEMENT

Judy Ellen Nelson

ABSTRACT: Major changes in the Bureau of Land Management's Rangeland Program put emphasis on economic analysis to increase the effectiveness of each program dollar spent. Economic screens focus the analysis effort and the internal rate of return is used as a tool to prioritize rangeland investments. A major grazing fee review and evaluation will provide the first comprehensive look at the value of public grazing lands since 1966.

INTRODUCTION

A year and a half ago, one of the more dramatic changes in Bureau policy in recent years occurred with the arrival of the Reagan Administration. Since then, Bureau personnel have been reorganized, budgets have been rearranged, and several programs--including range--have issued revised policy statements or regulations indicating a new program direction. Whether directly or indirectly, each of the changes that have and are occurring will influence range economics in the Bureau of Land Management (BLM). Within this same time period, the Bureau, together with the Forest Service, has begun a review and evaluation of the current grazing fee formula, as required by the Public Rangelands Improvement Act of 1978. One part of the grazing fee formula study is an appraisal of fair market rental values for public and private grazing lands in the Western United States. This appraisal is the most intensive collection of grazing value data since 1966.

RANGELAND MANAGEMENT POLICY CHANGES

Foremost in the Administration's efforts to improve the Federal Government are those aimed at increasing the effectiveness of each program dollar spent. Within the Bureau's rangeland management program, increased emphasis on cost-effective measures is most apparent in two recently released policy statements: a final grazing management policy and a draft rangeland improvement policy. Under the new grazing management policy, grazing allotments will be divided into three categories on the basis of their current resource situation and potential for resource and economic improvement. Lands with little potential for improvement, either because they are already producing near their high potential or because improvement is biologically or economically prohibitive, will be managed at the level needed to maintain current productivity. Most of our intensified funding and management efforts will focus on lands that are not producing near their potential and can be cost-effectively improved. New economic analysis procedures outlined in the draft rangeland improvement policy will help determine which allotments can produce the greatest return on the dollar and where the dollars should be invested first.

Rangeland Improvement Policy

The new economic analysis procedures were designed to both simplify our procedures and correct several weaknesses in existing analysis procedures. We appreciate the assistance of several members in the audience today. Fred Obermiller of Oregon State University chaired a special range economics task force appointed by Dave Tidwell, Special Assistant to the Director, to work with the BLM to develop realistic procedures. Other university professors who graciously invested their time and effort in this cooperative endeavor were Bill Champney of the University of Nevada, Bruce Godfrey of Utah State University, Jim Grey of New Mexico State University, Neil Rimbey of the Idaho State Extension Service, and Del Gardner of the University of California, Davis. A major objective of the special BLM-university task force was to design procedures that would bring the proposed range improvements in line with budget expectations while producing the greatest economic, social, and resource improvement per dollar expended. An additional sideboard on the procedures were that they could be understood and implemented by resource specialists and would not require economic expertise at the District level.

The Rangeland Improvement Policy first uses economics to help make a preliminary categorization of allotments, which begins very early in the planning process. Using available resource information and consultation with livestock operators and others, range conservationists estimate what types of improvements would be needed to eliminate existing resource use constraints. Anticipated benefits are compared with the probable costs of the improvements to determine the allotment's potential for positive economic return. Since one of the objectives of this early screening of allotments is to identify those where improvement efforts cannot be economically justified, range conservationists are asked to apply two common sense rules to their calculations: (1) Would the estimated improvements exceed the current selling price of private lands producing comparable forage? (2) Would the improvements cost more than the capitalized private grazing land lease rate, with an adjustment factor for non-livestock benefits?

Judy Ellen Nelson is Rangeland Economist, USDI, Bureau of Land Management, Washington, D.C.

Economic screening of allotments becomes finer throughout the planning process as more information becomes available and the proposed improvement packages become more specific. Emphasis is placed on least-cost methods of achieving desired allotment objectives and on ranking the allotments for improvement. Benefit/cost analyses are performed for each improvement plan, or "management package." Generally, State or regional values for grazing, wildlife, and recreation are used to calculate benefits. More localized values may be used to calculate benefits when this information is available and documented. Costs are computed from recent improvement expenditures. Management plans that cannot pass a 1:1 benefit/cost screen at this point cannot be included in a final resource management plan unless justified by overriding social or resource considerations.

Allotment improvement packages are preliminarily ranked by their internal rate of return. District Managers can adjust these rankings, in consultation with District Grazing Advisory Boards, to meet special resource needs, social considerations or to improve implementation schedules. All reasons for adjustments in the ranking are to be recorded so that the process can be replicated if necessary.

The final economic screen occurs as part of the budget process. More resource information has become available and allotment improvement packages now include specific range improvement projects and better cost estimates. Additional economic information has become available through the concurrent planning and environmental impact statement processes. Examples of improved benefit/cost estimates may include seasonal forage values developed through ranch budget linear programming analysis, or hunter day estimates developed in consultation with State wildlife agencies. The improved estimates are again subject to economic analysis. Once again, allotment improvement packages are arrayed according to economic criteria, with adjustments allowed to meet resource and social considerations. These packages are scheduled for implementation on both a State and District level in conjunction with annual budget allocations to each State. Once again, all decision steps are fully documented.

One element of the economic analysis procedures that gave us the most difficulty (in terms of reaching a workable consensus) was the value to be assigned to nonmarket outputs. Several ways of valuing nonmarket benefits were examined. Assigning no value to these outputs and placing more emphasis on the political process was not selected because of the problems it would create in the budget justification process. Valuing non-market output at the opportunity cost of the livestock forage foregone to produce these benefits was examined, but discarded since an opportunity cost is not a true measure of value unless very rigorous conditions are met. The Forest Service's Resource Planning Act (RPA) values were chosen as the most acceptable values unless more local values are available.

A second element of debate was how to provide an incentive for private contributions toward rangeland improvements. The Department of the Interior's policy is to encourage contributions for range improvements as a way of stretching the Federal dollar. In the draft policy, the manager considers contributions as an additional factor influencing the final ranking. Whether this provides enough incentive for contributions is still a matter of debate. The concept of financing allotment improvements through matching Federal-private funding is currently being examined.

PLANNING AND ENVIRONMENTAL IMPACT STATEMENTS

The planning process has undergone a transition similar to the range program. Analysis for land-use plans and environmental impact statements is becoming less encyclopedic and much more focused on issues that have been identified through public participation at the local level. Economics is expected to play an earlier and increasingly important role in planning as a screening device to achieve maximum returns from Federal expenditures. The Washington Office will concentrate on providing analytical tools and standards, but will not mandate specific economic procedures.

We are in the process of developing two tools to aid field managers in analyzing the impacts of BLM's resource decisions on the ranching community. A ranch budget questionnaire has been prepared and approved by the Office of Management and Budget. This questionnaire has been widely distributed to obtain the professional evaluation of experts in the field and we hope to begin field testing the questionnaire soon.

We are also developing a user-friendly linear programming package. The program will allow users that are not computer experts to use the data gathered through the questionnaire to develop linear programming models. We will expect our field economists to solicit review of their models from local universities and other experts.

GRAZING FEE REVIEW AND EVALUATION

The Public Rangelands Improvement Act of 1978 established the current grazing fee formula for the Forest Service (FS) and BLM for the grazing years 1979 through 1985. Section 12b of the Act requires, "No later than December 31, 1985, the Secretaries (Department of Agriculture and Department of the Interior) shall report to the Congress . . . their evaluation of the fee established in Section 6 of this Act (the current formula) and other grazing fee options, and their recommendations to implement a grazing years." (Public Rangeland Improvement Act 1978)

The review and evaluation initiated by the Forest Service and the BLM in response to this charge has four tasks. The first is to evaluate the current fee formula; second, to establish fair market value (FMV) and the formula's closeness to this value; and, third, to evaluate other fee options. The final action is to recommend a fee schedule for 1986 and subsequent grazing years.

The review of the current fee formula began last year with an evaluation of the indices used to compute fees in the current formula. From December 1981 to February 1982, the U.S. Department of Agriculture's Statistical Reporting Service surveyed 12,000 ranching operations in portions of five Northern Great Plains States to check the validity of the forage value index. Preliminary analysis of the data collected show that factors such as landlord services, the length of the lease, size of operation, etc., significantly influence private grazing lease rates. We intend to perform further statistical analyses of the data to determine factor relationships.

Our preliminary analysis also showed that "average" private grazing lease rates are lower than the "reported" private rates. We obtain "reported" rates through the June Enumerative Survey, which is conducted annually to obtain leasing information needed to update the private grazing land lease rate used in the grazing fee formula. As a result of the preliminary analysis, this year's Survey of the 16 Western States included additional questions for measuring the consistency of the difference between reported and average rates and the validity of continued use of the June Enumerative Survey results in the grazing fee formula.

We are just beginning to develop methodologies for analyzing other grazing formula indices. The producers' price index will be reexamined, both in terms of the relevance of the cost of production items that were included and the possibility of developing regional indices. The data series used to compute the beef cattle price index is also being examined and compared with alternative data series.

Evaluation of the "fair market value" of Federal grazing lands will be one of the most difficult components of the grazing fee study. Fair market value was last established in 1966 after a survey of over 10,000 ranchers westwide. The BLM and the Forest Service have attempted to maintain a fair market value factor in the grazing fee formula by using indices to update the 1966 value. The accuracy of indexing, however, becomes increasingly suspect as the gap between the present and the time of the original survey widens. Consequently, one of the reasons that the current fee was established on a 7-year trial basis was to allow time for "the Secretaries to refine their data on the value of public grazing." (U.S. Congress, House, 1978) The BLM and the Forest Service have initiated a fair market rental value appraisal of public grazing lands in the West to accomplish this task. This is the first major data collection effort since the 1966 Western Livestock Survey. The appraisal is similar to the 1966 approach, which used a survey of western ranchers as a proxy for a comparative market value appraisal.

Agency appraisers will identify, locate, and obtain details of private grazing leases from both lessors and lessees. Information to be collected will include specifics of the lease, including such items as rental rates, length of the leases, rights and obligations of both lessor and lessee, season of use, periods of use, distance from lessee's base operation, private range use in conjunction with public lands, maintenance of range improvements, class and number of livestock, unit price, payment schedule, and a physical description of the land. Data on between 30,000 to 100,000 leases will be computerized. Although we will rely primarily on the professional expertise of our appraisers, the lease data will be subjected to a variety of statistical analysis procedures focusing on the determinants of grazing values.

The identification and evaluation of other fee systems as required by the PRIA will primarily center on grazing fee systems currently being used by State, local, and other Federal Government agencies in the Western United States. Colorado State University (with Tom Bartlett as principle investigator) was awarded a contract in February 1982 to identify, describe, and evaluate these grazing fee systems. The results of this study will also be used to help the BLM and Forest Service evaluate the administrative feasibility of the identified fee systems. Additionally, the identified fee systems will be measured against Congressional and Federal standards such as the stabilization and protection of the western livestock industry, equitability to grazing users and other users of the public rangelands, level of range improvements, rights and obligations of the parties, and levels of program expenditures and receipts.

The Forest Service and BLM will be working closely with the Economic Research Service in the development of representative western ranch budgets. These budgets will be formulated as linear programming models and will become the basis for assessing the impacts of changes in grazing fees on livestock operators. Shadow prices from these budgets will also be used to verify the appraisal values and may become the data used in a grazing fee option.

Concerns of the livestock industry, public interest groups, and other interested parties affected by or interested in this effort will be identified throughout the grazing fee review and evaluation. Ongoing public participation in informal discussions and briefings will advise the public about the status of the review and provide an

opportunity for them to share their ideas in resolving concerns, identifying alternative fee options, and developing final recommendations.

The agencies' goal is to have a final report for submission to Congress by December 1984. This will provide the Congress a full year prior to the 1986 grazing season to act on any recommended fee schedule.

RESEARCH NEEDS

I would like to conclude my speech with a few ideas about what I consider to be the major economic research needs in rangeland economics.

Demand analysis.--The grazing of livestock on public rangelands has been declining since records have been kept. Reasons for this decline, i.e., whether they be agency policies, a diminishing resource base, or a lessening demand for use or possession of grazing preferences, is uncertain. Continuation of declining demand for forage resources would have major policy implications for federal investment in public rangelands and in pricing decisions. The sensitivity of demand for grazing and other rangeland resources to pricing decisions needs to be addressed. This is a difficult problem because the impact of Federal prices on the private market must be determined. Arguments are made that the level of Federal grazing fees increases, decreases, or has no effect on observed private prices. We need theoretical and empirical research to resolve this debate.

Institutional Arrangements.--The Sagebrush Rebellion and the renewed call for private ownership of public lands have focused attention on the benefits and costs of alternative institutional arrangements. Many of the issues raised concern tenure rights to land use and how tenure influences investment and conservation decisions. Sound data for resolving these issues are lacking. What is needed is research on the best institutional arrangements or land management policies. With a shrinking public dollar devoted to range resources, policies that meet objectives with reduced Federal expenditures may become increasingly important.

Research in institutional arrangement, however, should not focus exclusively on the profit maximizing economic unit. Seventy-four percent of BLM permittees use less than 500 animal unit months (AUM's) annually: the average is 127 AUM's, or approximately 10 cows grazing a year. These figures raise the question of the appropriateness of treating the hobby rancher and the business rancher equally.

Nonmarket values.--Estimations of resource values, particularly the estimation of nonmarket values (including those associated with ranching), need to be improved before resource managers will have much confidence in their use in budget allocations. Especially important is the assurance that the measurement of values is consistent between resources so that nonmarket resources are not over or under valued in management decisions.

Much of the controversy surrounding ownership of the public ranges is an argument over the nonmarket values associated with the public range. As Gary Libecap (1981) argues, the "profit maximizing decisions of ranchers also maximize the net social value of rangeland and its contribution to production [and since] . . . there appear to be no significant external effects from private range use, ranchers (unlike bureaucrats) incur full social cost and benefits from their efforts." If this statement is true, few economists (or members of the general public) would argue with private ownership. But, as M. M. Kelso states in his article "Current Issues in Federal Land Management in the Western United States," written in 1947 (when there was "sharp and widespread conflict over the very existence of federal landownership in the West"):

> "When grazing is the only use on federal lands, it can be legitimately argued that, in line with long established national policy regarding agricultural land in the United States, it should be privately owned. But suppose this grazing use is only one of several uses on the same area, the others being watershed protection and water yield which are of equal or, what is frequently true, of greater value than grazing use?"

Kelso goes on to argue that one of the criteria for land remaining in public ownership is if the benefits of managing the land for multiple-use values (including the nonmarket commodities) are higher than the production lost in the private sector. We require much more knowledge of nonmarket range values before the benefits and cost of alternative ownership arrangements of public land can be fully examined.

Bioeconomic relationships.--William Martin (1972) states that "...agricultural economists finally quit most work on the (range economics) problem when it became evident that no consistent set of empirical data was available--or was likely to become available--with which to work." My recent review of rangeland literature has convinced me that the situation has not materially improved since Martin made the statement. I am also convinced, however, that the fault must be shared by economists who are unable to articulate what data is necessary to develop the bioeconomic models that could provide answers to important policy questions.

We need to design experiments that will develop resource/economic tradeoff functions. Economists must be willing to participate as members of interdisciplinary teams in designing experiments and monitoring the experiments if the end results are to have much utility.

In closing, what is lacking in rangeland economics research is the information needed to resolve basic policy questions and constantly recurring issues concerning public land management. To quote a remark made over 35 years ago" ... The most important place for study by western agricultural economists (is)...the make-up, organizational setting, and limits to the area of decision open to this agency ... if private uses of federal resources in the West is ever to be anything but a ceaseless bickering in the political arena."

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MULTILEVEL ANALYSIS OF FOREST AND RANGELAND RESOURCES

John G. Hof, Linda A. Joyce, Gregory S. Alward, and Thomas W. Hoekstra

ABSTRACT: This paper presents a multilevel analytical system for national-level forest and rangeland planning. This approach is a compromise between completely decentralized planning--where national plans would merely be summations of local plans--and centralized planning--where local output levels and budgets would be controlled by a national plan. The ecological analysis of resource production is developed at the most decentralized (local) level of planning. This provides the data base for local-level mathematical programming models of resource allocation. These, in turn, are used to generate management alternatives, characterized by an output set, that are used as choice variables in higher level mathematical programming models. The purpose of this system of models is to determine efficient production possibilities for the entire multilevel system. Because this system concentrates on efficiency considerations, a multilevel socioeconomic impact model structure is also described that would address equity-oriented considerations.

INTRODUCTION

In this paper, the central decision made through renewable resource planning is taken to be the selection of the output vector (mix) to be produced, and the determination of management actions necessary to produce it from the land base. In this context, the output mix includes land conditions as well as outputs that are removed from the land base. It is also assumed that the decision criteria in renewable resource planning fall into either efficiency criteria (e.g., costs and benefits) or equity criteria (e.g., socioeconomic impacts).

National renewable resource planning is a staggering problem because of conflicting needs for detail and scope. On the one hand, analyzing relatively small areas of land (such as a National Forest) is appealing because of the relative detail, resolution, and accuracy that can be achieved. On the other hand, concerns of regional and national scope may differ from local concerns, which increases the desirability of an analysis that can capture absolute and comparative advantages between smaller land units. Thus, local-level plans cannot simply be added up into a national plan.

John G. Hof and Gregory S. Alward are Research Foresters, Linda A. Joyce is Range Scientist, and Thomas W. Hoekstra is Project Leader at the Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; station headquarters is in Fort Collins, in cooperation with Colorado State University.

The ideal solution to this dilemma would be the use of a single national analysis that is capable of achieving high levels of resolution and detail. Because this is unworkable at this time, a multilevel modeling approach is suggested here. This approach attempts to incorporate national and regional discretionary control, a high degree of resolution and detail, and consistency between different levels of planning.

Work by Wong (1980) in the USDA Forest Service Southwestern Region provides an excellent start for the modeling approach discussed here. In general, he suggests that detailed production analysis should only be implemented at the lowest levels of the management organization, and that the regional- and national-level analyses should focus only on control through the selection of discrete management alternatives provided by the lowest levels of the organization.

Figure 1 depicts the key features of the proposed analytical approach. The "Primary Models" quantitatively describe the resource output responses to alternative land management prescriptions. The primary models for predicting range production responses are discussed further in Joyce (in press). The predictions from the primary models provide the data for the "Production Possibilities Generators" (PPG's), which are used, in turn, to construct discrete management alternatives for consideration at the regional/national level. Most logically, the PPG's would be mathematical programs that can generate "optimal" alternatives, given various objective functions and/or constraints. The regional/national-level models would also most logically be mathematical programs, as discussed further below. The multilevel system of mathematical programs is obviously oriented towards "efficiency" considerations. In order to incorporate "equity" considerations, a system of socioeconomic impact prediction models is also included, as shown in figure 1. The primary models, the multilevel optimization models, and the system of socioeconomic impact models are discussed in more detail below.

PRIMARY MODELS

Land management activities affect the structure and function of an ecosystem, and changes in the ecosystem are reflected in changing levels of resource outputs (fig. 2). Analytical techniques predicting single resource production quantify those pathways in figure 2 pertaining to the single resource, such as timber or wildlife. A consideration of the impact of this single resource management on other pathways and on the joint production of resource outputs is necessary to evaluate the total impact of management on

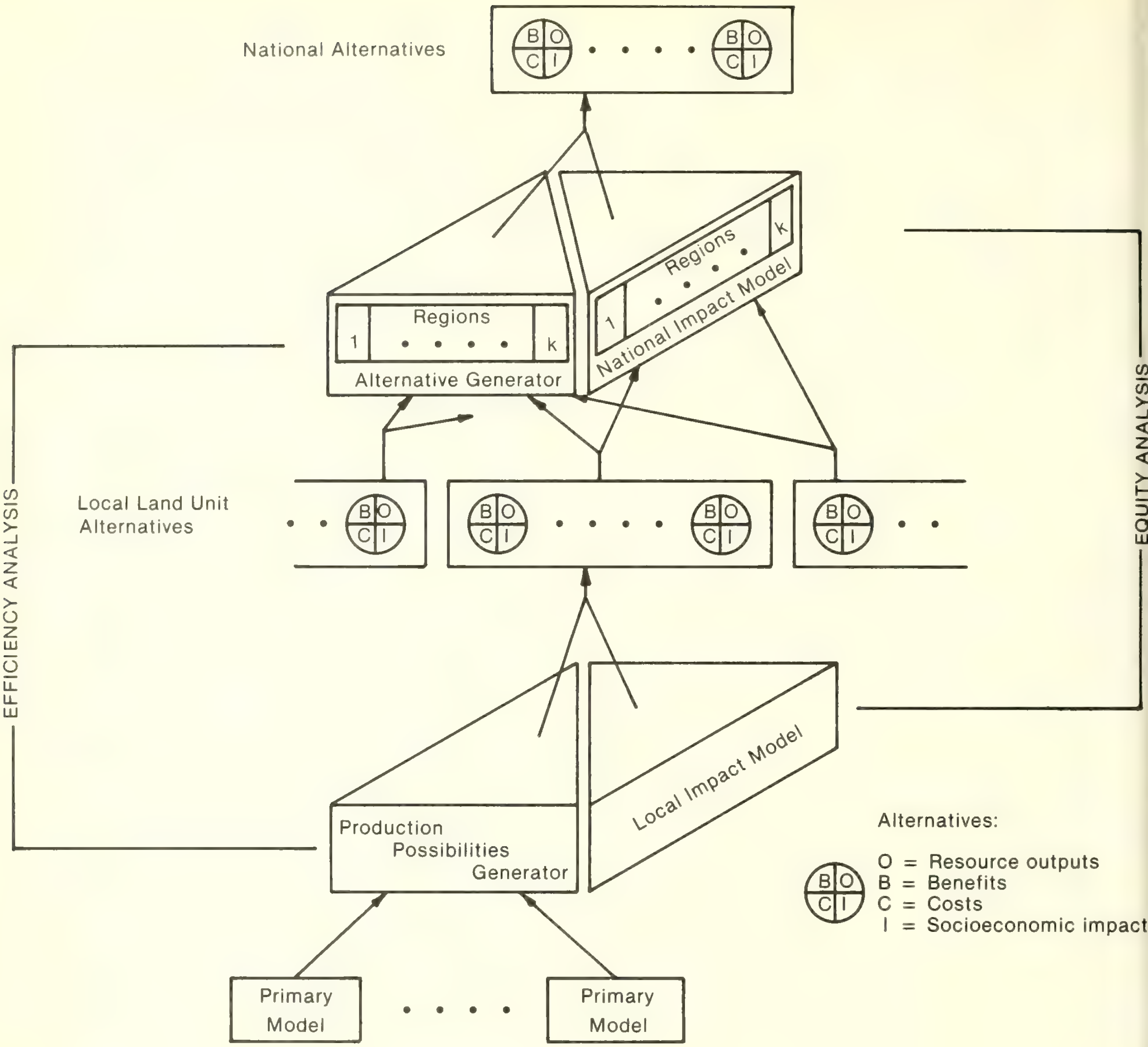

Figure 1.--Multilevel modeling structure for national-level planning analysis.

the ecosystem. This is the role of the primary models.

The three types of primary models are simulation models, statistical models, and models based upon intuitive approaches. The choice of the type of primary model is a function of the kind and amount of ecological theory and data available. A statistical model may be the best choice when there is sufficient empirical data to develop the required functions for joint resource production. A simulation model may be the best choice when the mechanisms related to the changes in resource outputs can be mathematically defined. Where little or no empirical data and only limited knowledge of mechanistic relationships exist, the model may be limited to an intuitive approach.

Simulation models.--These models represent an ecosystem as a collection of compartments that are linked by flows of materials, such as carbon or energy, contained in the compartments. The dynamics of the flows are defined by a set of rate equations representing known or postulated biological and physical mechanisms. The rates of flow can be a function of the levels of material in the compartments, or system-independent factors such as temperature and insolation. Simulation models are always constructed using simplifications of the real system. Manipulations of the completed

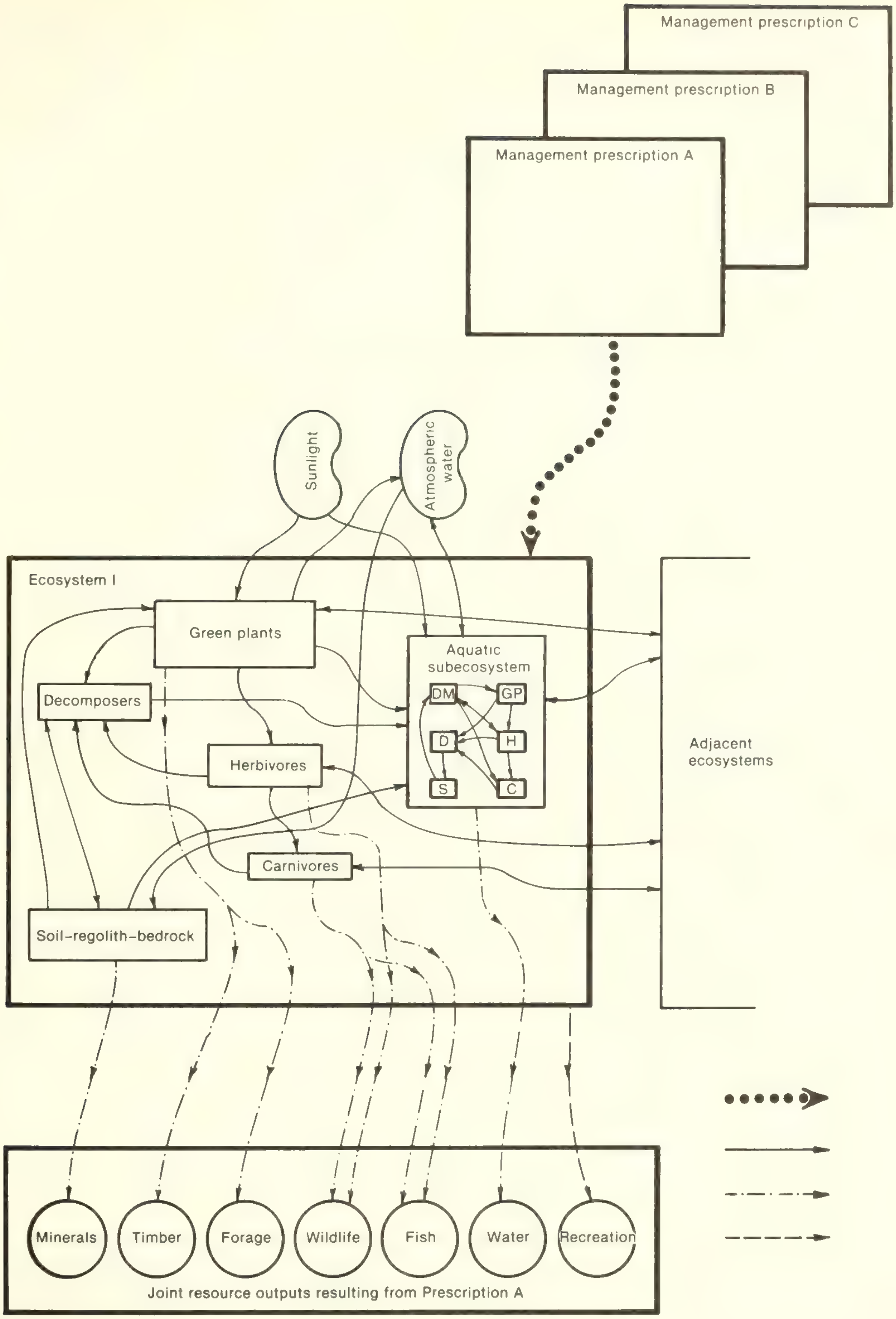

Figure 2.--Ecosystem structure and resource outputs. Management prescriptions applied to an ecosystem alter the array of simultaneously produced outputs by changing ecosystem structure and functioning.

ecosystem model represent the logical conclusions and extensions of our understanding of the ecosystem processes expressed in that model. Manipulations of the model help broaden our understanding of the mechanisms operating in the system.

Statistical models.--These models define empirical relationships between state variables or the compartments of the system. Techniques used to generate such models include multiple regression, time series analysis, and discriminant analysis. Often implicit in such models are assumptions about the functional form of the relationship between the variables. For example, a common assumption in regression analysis is that a dependent variable is a function of a linear combination of one or more independent variables. Except for models based upon time series analysis, most statistical models can provide only point estimates for state variables, i.e., the value of the variable at some fixed time. The accuracy of estimates from statistical models is related to both the validity of the assumptions used in the model, and the accuracy and number of observations that are used to estimate the parameters of the model.

Models based upon intuitive approaches.-- These models may be the acceptable alternative in those situations where theory and data are so sparse that neither simulation nor statistical models can be constructed. An intuitive approach, such as an interdisciplinary team approach, relies on experts to integrate their experience and the state of the art in estimating the point estimates or the functional relationships of the state variable response to various management prescriptions.

Within the analytical system, the results obtained from the primary models form a data base used in the PPG's. As primary models are the only level at which resource production information enters the modeling hierarchy, it is imperative that this information be organized in the most efficient manner and that it be as accurate and precise as possible. Primary models previously have focused on single resource production. Hence, the results from these single resource models require an integration process to form the multiresource data base for the PPG's. This integration process must standardize the primary model manipulations so that the same type of management activities are implemented in each primary model. The interdisciplinary team approach has served as a qualitative integration process. Future primary models for this analytical system may still focus on single resources but should contain a common description of each ecosystem studied, allowing for a more quantitative integration process. Developing primary models capable of simulating the simultaneous production of resources in any forest or range ecosystem is a research challenge.

MULTILEVEL OPTIMIZATION SYSTEM

A number of papers describe mathematical programming procedures that would be appropriate for the PPG's in figure 1. (See, for example, D'Aquino 1974; Johnson and others 1980; Ashton and others 1980; Kent 1980.) In application, both the PPG's and the higher level model(s) would most conveniently be linear programs, though this is by no means necessary. Each "alternative" generat by the PPG's is simply a vector of outputs that can be produced at an associated joint cost, a set of benefits, and a set of socioeconomic impacts.

Figure 3 depicts the linear programming matrix of a very simple version of a national model (Wong 1980). In this example, only two regions, two alternatives, and three products are included. Also, only one time period is included, and embellishments such as regional targets are not included. Expansion beyond the dimensions of this simple example is straightforward.

In figure 3, X_1 through X_4 are 0-1 variables representing selection or rejection of an alternative output vector with associated joint cost (F_i; i=1,4) for a given region. For example, X_1 represents selection or rejection of the entire output vector $A_{1,1}$; $A_{2,1}$; and $A_{3,1}$ in Region 1. Rows 5 through 7 set national "targets" on the three outputs (T, W, F). Row 4 places a budget constraint on the selection of alternatives, and row 8 is the objective function to be maximized. All of the matrix below the objective function row constrains the X_1 through X_4 so that each of them is between 0 and 1, and so that only one alternative can be selected for each region.

Because this is a linear programming model instead of a discrete optimization model, X_1 through X_4 may actually take on solution values between 0 and 1 but not equal to either. For example, X_1 and X_2 in figure 3 may solve with values of 0.6 and 0.4, respectively. This is interpreted as a partial acceptance of each alternative, the combination of which satisfies the "0-1 model constraints." This may suggest the construction of a new alternative that is subjectively constructed from X_1 and X_2, based on the solution values. Some means, such as re-solving the lower level model, would be needed to determine the cost and feasibility of the new alternative. No assurance can be made that this new alternative will be completely accepted in the national model. Its presence may actually cause changes in the solution values of any or all other variables as well. Resolution of this problem is an important research need in the development of the multilevel analytica system. The use of zero-one programming would avoid this problem, but the partial acceptance of alternatives may prove to be valuable information.

Consider the case where a continuous linear programming model indicates partial selection of a plan for a particular region. This would indicate that no single alternative at the regional level optimally met the national objectives but that a partial selection of plans did. This provides important information to planners at both levels. Two situations can occur in the higher level model that will cause partial selections. First, there may be no combination of complete regional alternatives that meet the national output targets; however, partial selections do. Second, while a combination of complete regional alternatives might meet the national targets, a

	Region 1		Region 2		Outputs			Type	RHS
	X_1	X_2	X_3	X_4	T	W	F		
Timber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	-1			=	$0=K_1$
Wildlife	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$		-1		=	$0=K_2$
Forage	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$			-1	=	$0=K_3$
Budget	C_1	C_2	C_3	C_4				$\leq$	K_4
					1			$\geq$	K_5
						1		$\geq$	K_6
							1	$\geq$	K_7
Obj. Fun.	$-F_1$	$-F_2$	$-F_3$	$-F_4$	F_5	F_6	F_7	-	MAX
0-1	1	1						=	1
Model constraints			1	1				=	1

Figure 3.--A simple national model, where the X_1 through X_4 are 0-1 variables representing selection or rejection of an output vector $A_{i,1}$ through $A_{i,4}$ (i=1,3), respectively. The F_j are the objective function coefficients, and the K_1 through K_7 are right-hand sides (RHS).

partial selection(s) might exist that results in a higher present net worth (maximizes the objective function to a higher degree). Consider solving the same problem with zero-one programming. In the first case, an infeasible solution would result, indicating that a new alternative(s) is needed. However, in this case, no information on the nature of that new alternative would be supplied to the analyst. In the second case, one alternative would be selected for each region and a feasible solution obtained, but the solution would result in a lower present net worth than if partial selections were permitted. The zero-one programming approach does not indicate that better regional alternatives may exist.

The principal advantages of a multilevel optimization such as this, is that the detail and high resolution of local-level analyses are preserved, but national discretionary control is still allowed--the national plan will not simply be a summation of local plans. The implied national model reflects a great deal of detailed production analysis, but is itself of very workable size and complexity. And, any national model solution is automatically disaggregatable to (and consistent with) local management plans. The principal shortcoming of a multilevel optimization approach is that limiting the national analysis to a finite number of discrete choices may overlook desirable options and thus lead to suboptimization.

SOCIOECONOMIC IMPACT SYSTEM

The preceding discussion has emphasized the concern for being efficient regarding the costs incurred to productively manage forests and rangelands. In general, the costs of delivering goods and services from forests and rangelands to ultimate consumers are affected by the location of these management activities, which are captured by the multilevel optimization system described above. Beyond this, however, planning criteria may extend beyond pure "efficiency" concerns to matters involving the utilization of labor and industrial capacity, and to the manner in which benefits and costs are distributed among members of society. Thus an "equity" or "distributional" analysis confronts such issues as: estimating how a management program might affect regional unemployment or idle industrial capacity; the dependency of communities on programs or their vulnerability to program changes; the generation and distribution of regional income; and the extent to which resource management programs could be used as positive tools of regional economic policy.

To determine the distribution of the economic effects of forest management programs both regionally and among participants, a framework of structural models of economic activity is recommended here. A system, referred to as IMPLAN,

has been developed (Alward and Palmer, in press) to derive regional input-output models for the local areas affected by Forest Service programs. As illustrated in figure 1, impact models are used to estimate the socioeconomic effects of management alternatives at both the local land unit level (local impacts) and at the regional/national level (regional/national impacts). Since all impact models are constructed in the same manner from an internally consistent data base, the socioeconomic impact system produces a multilevel hierarchy of impact estimates. With these structural models, the distributional consequences of new or modified management programs can be traced in terms of income gains (losses) to industries and labor. Special attention is given to estimating employment effects by tracing impacts upon unemployed workers, occupational categories, and income groups, and the implications of these effects in terms of the issues noted above.

The general form of a regional impact model is given in equation [1]:[1]

$$\underline{X} = (C\underline{Y}^1) + (C\underline{Y}^2) + \cdot\ \cdot\ \cdot + (C\underline{Y}^m) \qquad [1]$$

The vector of gross outputs by sector for the region ($\underline{X}$) are determined from direct and induced changes in regional final demands ($\underline{Y}^n$, n=1, m) by applying the matrix of total requirements (C). This "open" matrix does not include the household industry. Induced changes in regional final demands ($\underline{Y}^n$, n=2, m), which arise from consumptive spending of household income, are determined iteratively as a function of regional income, as shown in equation [2]:

$$\underline{Y}^n(n=2,\ m) = f(\underline{I}_r^n,\ n=1,\ m-1), \qquad [2]$$

The function (f) specifies the resident populations propensity to consume locally produced outputs. The total effects of induced spending are captured when the estimated changes in gross output approach zero, as in equation [3]:

$$|\ (C\underline{Y}^m)\ | \longrightarrow 0 \qquad [3]$$

Direct changes in regional final demands ($\underline{Y}^1$) are estimated from changes in output production, resource uses, and government purchases associated with a management program as determined by the multilevel optimization system. Equation [4] provides the identity for changes in direct final demands as a function of timber harvest (T), forage grazing (G), mineral, oil, and gas extraction (M), water flow (W), recreation use (R), and government purchase (E):

$$\underline{Y}^1 = g(T,\ G,\ M,\ W,\ R,\ E) \qquad [4]$$

[1]Matrices and vectors are denoted by capital letters, with vectors distinguished by underscoring (e.g., $\underline{Y}$); superscripts indicate computational iterations.

Regional employment ($\underline{L}$) is determined from change in gross output, as shown in equation [5]:

$$\underline{L} = h(C\underline{Y}^n,\ n=1,\ m) \qquad [5]$$

The function (h) accounts for employment drawn from the regional unemployment pool and in-migration induced by employment opportunities. The employment effects can likewise be expanded to include occupational categories and income groups. Regional income from employee compensatic ($\underline{I}_c$) is estimated from the predicted employment effects, as given by equation [6]:

$$\underline{I}_c = i(\underline{L}) \qquad [6]$$

Equation [7] shows that regional income from property ($\underline{I}_p$) is a function of gross output:

$$\underline{I}_p = j(\underline{X}) \qquad [7]$$

Total regional income is the sum of employee compensation and property-type income.

As can be deduced from the equations above, applications of the model to estimate regional economic impacts are conducted independently for each study area (e.g., for a local economy affecte by a National Forest's program). Significant leakages via import and export flows are characteristic of such areas. These flows represent the interdependencies between regional economies represented by such factors as trading patterns and commuting behavior. To incorporate these aspects, the methods for constructing impact models are being expanded to obtain interregional input-output formulations. This enhancement will permit a more complete tie between the estimation of regional economic impacts and locational shifts in resource production or use investigated by the multilevel optimization system. Futhermore, the explicit incorporation of interregional feedback flows between regions gives a comprehensive estimat of local effects. On the basis of this information the potential to discern the social consequences of resource management programs is enhanced.

CONCLUSION

Previous national planning analyses have tended to analyze one resource at a time and have tended to be predictive. One important exception was the NIMRUM effort attempted in the 1980 USDA Forest Service RPA Assessment Analysis of "Multiresource Use Interactions" (Ashton and others 1980). The multilevel analytical system could be regarded as an extension or development of this effort--an extension oriented toward simplification and increased workability. It leaves the detailed problems of land allocation and management practice scheduling to the lowest land unit level of analysis. At the regional and national levels, the point of focus is the problem of selecting the output mix. By limiting the regional and national analyses to this problem, the models at all levels are reduced to workable size and complexity, yet a considerable degree of discretionary control at the higher levels of analysis

s preserved. The principal shortcoming of the multilevel optimization system is that limiting the choice variables at the regional and national levels to selection from a finite number of alternatives may cause the analysis to overlook desirable options that are, in fact, feasible.

In limiting most of the production possibilities analysis to the lowest level of analysis, some interaction effects between land units may be ignored. Examples of these effects are (1) enhanced migratory bird populations resulting from coordinated habitat management on a given flyway and (2) downstream water quality effects resulting from timber harvesting. Nonetheless, the multilevel system solves the problem of disaggregating national analysis results across smaller land units, and it avoids problems of inconsistency between levels of analysis that would occur if these analyses were performed independently.

Finally, this paper has discussed a general modeling approach. It should be noted that an application of this approach has been proposed as part of the 1989 Assessment of Forest and Rangeland Resources carried out by the USDA Forest Service, mandated by the Resources Planning Act (RPA) of 1974. This application will concentrate on multiresource interactions considerations in identifying opportunities for improving the future renewable resource situation. It is currently being referred to as a "National Assessment Multiresource Model" (NAMM), and is viewed as an augmentation of the more functional, predictive analyses that have traditionally been (and will continue to be) included in national assessments of forest and rangeland resources.

A modeling approach that is similar to that described here is being developed for the 1985 RPA Forest Service Program. This effort will utilize the FORPLAN models being built for use in Forest-level Land Management Planning as the lower level models. The higher level model is the ADVENT budgeting model. IMPLAN models will be used at the forest, regional, and national levels.

Since NAMM will be used in the 1989 Assessment, it must account for all forest and rangelands, not just the National Forest System. Also, while the emphasis in ADVENT is on solving a budgeting problem, the emphasis in NAMM will be on analysis of production potentials, resource allocation, and economic efficiency. It is anticipated that NAMM might be linked to the 1990 Program budget analysis to improve the allocative efficiency of the 1990 Program.

As in the 1985 ADVENT model, it is anticipated that NAMM will utilize FORPLAN-generated alternatives for National Forest System lands. For other forest and rangelands, it is anticipated that one linear program will be built for each Forest System Region to generate alternatives. Since these lands are not under direct Forest Service control, only low-resolution management opportunities need be identified. It is likely that the NIMRUM software, developed for the 1980 RPA Assessment, will be used for these regional linear programs.

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MULTIRESOURCE PRODUCTION AT THE REGIONAL LEVEL

Linda A. Joyce*

ABSTRACT: This paper presents a modeling approach to analyzing the multiresource production response to alternative management activities used in national assessments of forest and range resources. Primary models are developed in a framework that integrates the current strengths in single resource modeling efforts.

INTRODUCTION

The Forest and Rangeland Renewable Resource Planning Act (RPA), as amended by the National Forest Management Act, requires the USDA Forest Service to assess the current and future production of all forest and range land resources. Assessing the range resource at the national level requires an approach which is capable of assessing the future range production on all forest and range lands, which is repeatable, and which accounts for interactions with other resources. This paper presents a modeling approach in which single resource models are integrated to represent multiresource production at the local level. These primary models are used together to develop the management alternatives to be analyzed at the national level. While demand information is also required in the assessment, this paper discusses only the models analyzing multiresource production.

BACKGROUND

The tasks specified in the RPA have been interpreted by Hoekstra and Hof[1] to require:

1. Current and historical inventory information on natural resources;

2. Future projections of current production and consumption patterns;

3. Opportunities for improving the future resource production situation, considering tradeoffs in production for all renewable resources.

Analyzing opportunities for improving future resource production requires a methodology capable of analyzing different alternatives for forest and range land management, under varying decision criteria. Such a model at the national level could examine the tradeoffs in production of all renewable resources.

In the 1980 Assessment (USFS 1980), the multiresource analysis of future opportunities was facilitated by the development of a large linear programming model, referred to as NIMRUM (Ashton et al. 1980). This linear programming (LP) model allocated acres of land in the entire forest and range land base by ownership to different management strategies based on the decision criteria of minimum cost.

Current resource management, multiresource outputs, and costs of production were estimated by regional interdisciplinary teams, using a set of procedural guidelines.[2] These current management activities formed the columns of the A-matrix in NIMRUM. Future resource demand information was supplied to the model. The NIMRUM model then allocated management activities to the entire forest and range land base in a way that the cost of management was minimized. The result of this analysis was one management alternative, composed of a set of management activities for units of land within the forest and range land base. This alternative suggested one strategy for improving resource production.

Within NIMRUM, the land base was divided into resource units on the basis of vegetation-ownership-condition-productivity classes. Kuchler's (1964) 107 Potential Natural Vegetation Communities were used. Ownership categories were: National Forest System (NFS) lands, Bureau of Land Management lands, other Federal lands, and State and Private lands. Four condition and four productivity classes were used. Current management was classified by the timber-range-wildlife strategies, of which there were 126 strategies possible. Because more than one management strategy could be currently used in each resource unit, the size of the NIMRUM model was large.

Two criticisms can be made of this model. One is the large size which limits the number of times the model can be run. The other concerns the subjective nature of the data base. The use of interdisciplinary teams may be the only alternative to generate such a data base; however, this method is subjective and the information is not easily updated.

*The author is a Range Scientist at the Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, Colorado.

[1]Hoekstra, Thomas W., and John G. Hof. 1982. Technical Requirements for National Assessment of Wildlife and Fish. RPA Assessment Staff Paper. February 15, 1982.

[2]USDA Forest Service. 1977. Book of Procedures Framework for Supply Analyses. Mimeo. Washington, D.C. 100 p.

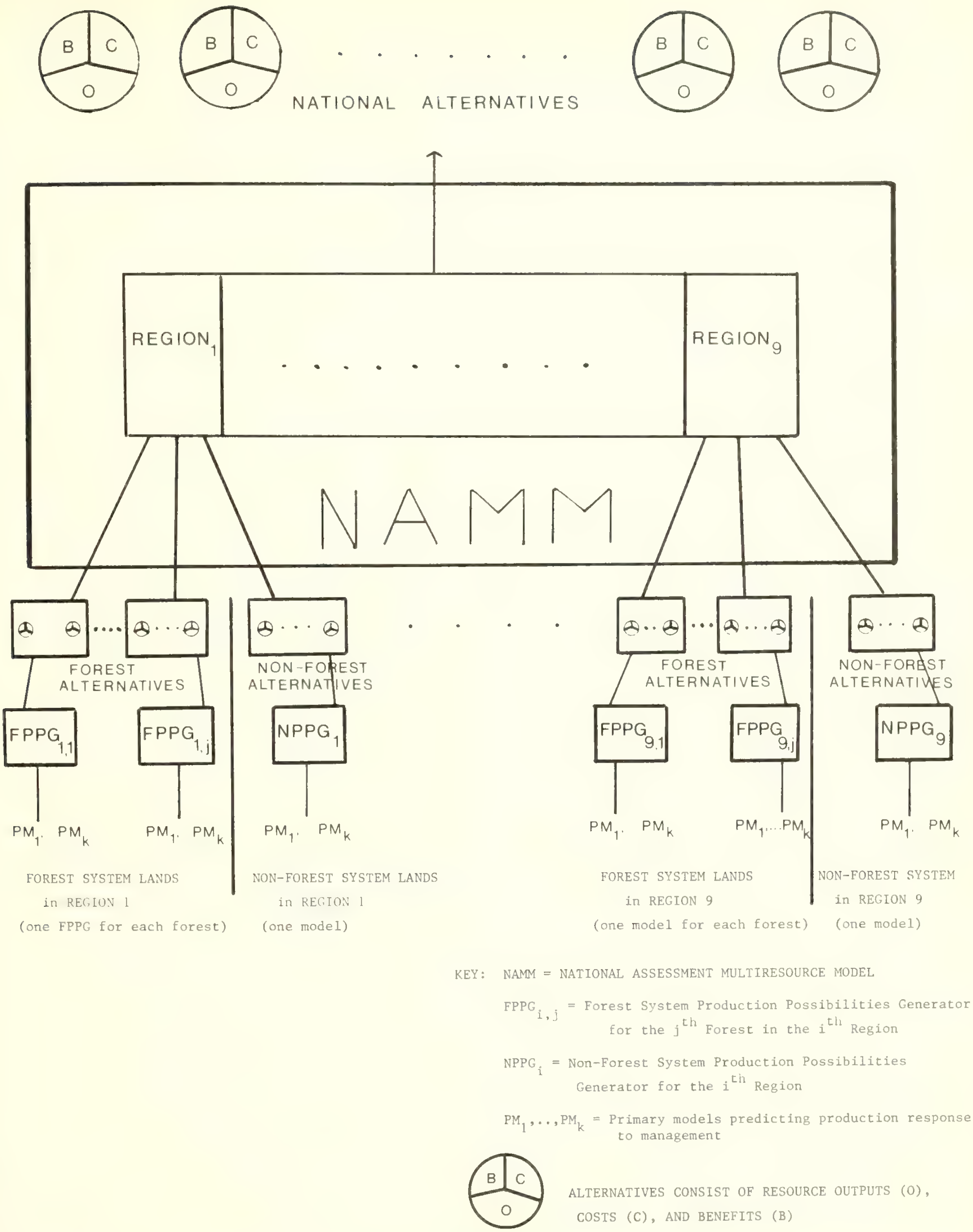

Figure 1. The multilevel analytical system.

Hof et al. 1982, in this symposium, proposed a multilevel analytical system for national level forest and range land planning (fig. 1). Within this hierarchy, regional/national level models allocate land management alternatives to ownerships. Because these models do not allocate management activities to acres of land, these models are small, and can be rerun quickly and efficiently. The local level LP models, referred to as Production Possibility Generators (PPG), allocate management activities to acres, and, consequently, are more detailed. Primary models develop the resource response information needed in the PPG's. Because primary models are the

only level at which resource production information enters the modeling hierarchy, it is imperative that this information be organized in the most efficient manner and that it be as accurate and precise as possible. This paper addresses the development of these models.

MULTIRESOURCE PRODUCTION

The LP model, referred to as Production Possibility Generator (PPG) in the multilevel system (fig. 1), can be solved to give the optimal set of management activities to be used in a particular land unit based on a particular objective, such as economic efficiency. The optimal set of management activities constitutes one management alternative for either the NFS land unit or the non-NFS land unit.

The multilevel analytical system is designed to receive input from the established National Forest System Planning Process. An example of a FPPG is FORPLAN, the LP model constructed by interdisciplinary teams as part of the forest planning process on each National Forest. FORPLAN is used to select a set of management activities for the entire National Forest, which are optimal in terms of some decision criteria. This set is called a forest-wide plan. Alternative forest-wide plans are selected by using alternative decision criteria, inputs (such as budget levels) or constraints in the FORPLAN model. For each forest-wide plan, the model provides a summary of costs, benefits, and outputs.

The established NFS Planning Process facilitates the development of primary models and the PPG for NFS lands. There is no similar process for non-NFS lands.

Non-NFS lands are under diverse managements, and future alternatives for these lands can be defined only by general assumptions. An example of a PPG would be a regionalized version of the NIMRUM model. The original model focused on the entire forest and range land base. This regional model would be used to select a set of management activities for the entire non-NFS land base within the region. This set could be called a regional plan for non-NFS lands. Alternative regional plans could be selected by using alternative decision criteria, inputs or constraints in the model. This production information on non-NFS lands could be used to define general opportunities rather than specifying precise management. For each regional non-NFS plan, the model would provide a summary of costs, benefits, and outputs.

These PPG's still require resource production information. Each column in the A-matrix represents the joint production of resources in response to the associated management activity. Therefore, the procedure used to develop this information must simulate the joint production of multiple natural resources.

The methods that have been developed to estimate the joint production of natural resources can be categorized as follows:

1. Interdisciplinary (ID) Team Approach. This approach uses the experience of each team member to predict the joint production of natural resources in response to management.

2. Multiresource Models. This approach attempts to aggregate functional models.

3. Joint Production Models. This approach attempts, in one model, to predict the simultaneous production of natural resources in response to management.

The ID team approach has been used by the Forest Service in its forest level planning process (Forest Service Planning Handbook FSM 1920) and in previous Assessments. It has been used by private corporations (Cooper and Zedler 1980), and by governmental and private groups together (Holling 1978). This approach, however, offers no way to update the production estimates other than going through the ID team exercise again.

The multiresource modeling approach attempts to aggregate single resource models. This approach to modeling ecosystem dynamics has been successful in several areas. Sullivan et al. (1981) adapted a forage model of a subterranean clover pasture in Western Australia and the Texas A&M Cattle Production System model for tropical conditions in East Africa. Eraslan et al. (1976) combined a hydrodynamic model of heat and salt transport with a population model of striped bass. In a large modeling project, five models were aggregated to simulate shortgrass prairie dynamics (Innis 1978). Sullivan et al. (1981) and Eraslan et al. (1976) aggregated models that were previously developed. In Innis (1978), the scientists building the models worked together initially to devise a set of common state variables to connect the models, and then constructed the models independently.

Analysis of joint production using ecosystem structure and function, the third approach, is a recent development. Progress in this area has been hampered by insufficient and inadequate data, and by lack of ecological theory. Long-term records of ecosystem response to management under controlled conditions are rare. Advances in ecological theory continue to be made, but, as yet, there is no single unifying theory about ecosystem structure and function that could be applied to all ecosystems (Joyce et al. 1982).

Multiresource models offer the most promising approach to the estimation of forest and rangeland outputs. Quantitative techniques predicting the production of natural resources have thus far focused on single resource outputs. These techniques in three functional areas have been reviewed by Alig et al. (1982) for timber, Hawkes et al. (1982) for wildlife and fish, and Mitchell (1982) for range. Within this multiresource modeling approach, research and existing data within the individual resource areas could be drawn upon to select and/or develop functional models.

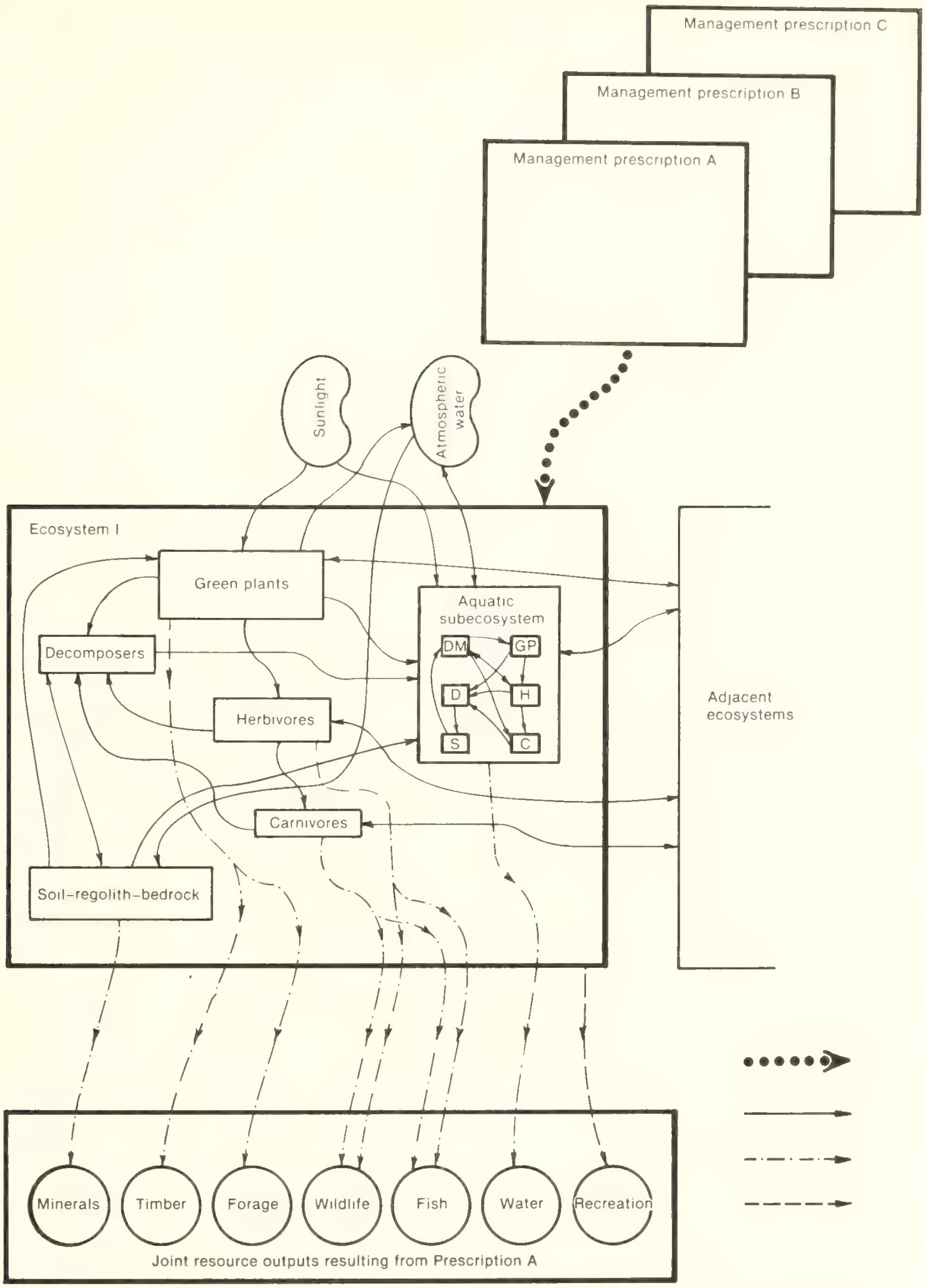

Figure 2. Management prescriptions, ecosystem structure, and resource outputs.

REGIONAL MULTIRESOURCE MODELS

The proposed framework addresses the development of primary models for non-NFS lands in each NFS region. These primary models would together estimate the multiresource response to management activities on non-NFS lands. This data forms the A-matrix of the PPG for non-NFS lands. Each regional plan generated in the PPG is to be used as a choice variable in the higher level LP models in the multilevel analytical system. At the national level, alternative management plans for NFS lands and non-NFS lands are analyzed together with a multilevel system.

Primary Models

The purpose of a primary model is to describe quantitatively an understanding of the impact of management on the ecosystem at the National Forest level in the forest planning process, or at the regional level for non-NFS lands in an assessment. Land management activities affect the structure and function of an ecosystem, and changes in the ecosystem are reflected in changing levels of resource outputs (fig. 2). Models predicting single resource production quantify those pathways in figure 2 pertaining to the single resource, such as timber or wildlife. A

consideration of the impact of this single resource management on other pathways, and the joint production of resource outputs is necessary to evaluate the total impact of management on the ecosystem. This is the role of the primary models.

Primary models are required to generate input to the LP models. An LP analysis implies certain assumptions about the data use in the LP model. Primary models must be constructed with these assumptions clearly stated.

The three types of primary models are simulation models, statistical models, and models based upon intuitive approaches. The choice of the type of primary model is a function of the kind and amount of ecological information and theory available. A statistical model may be the best choice when there is sufficient empirical data to derive the required functions for the joint production of resources. A simulation model may be the best choice when one can define mechanisms related to the changes in the state variables of the system, and when sufficient data exists for validation of the model. Where little or no empirical data and only limited knowledge of mechanistic relationships exist, the model may be limited to one based upon an intuitive approach.

Standard Protocol

The process of creating the primary models in the multiresource modeling approach would be facilitated by a standard approach across regions. This protocol would assure that the primary models were the best models that could be constructed to estimate multiresource production and provide the most appropriate input to the LP models.

Within each region, a multiresource framework would be used by an interdisciplinary team to facilitate selection and/or development of single resource models. The development of the single resource models would be the responsibility of each resource specialist.

Six steps outline a standard approach:

(1) Each resource specialist on the ID team defines the set of resource outputs and management prescriptions to be considered at the regional level.

(2) Each resource specialist on the ID team defines the variables from other resources needed to predict their own resource.

(3) The ID team defines the set of resource outputs and management activities to be considered in the multiresource framework.

(4) Each resource specialist chooses the type of model to be built or selected in each functional area.

(5) Each resource specialist constructs and documents the single resource models.

(6) The adequacy of each model is tested.

Steps 1 and 2 are important in quantifying this process. The many problems associated with integrating primary models for different resources can be avoided or simplified if the primary models define relationships between components of the natural resource system which contain, at any time, measureable quantities. These components are usually called state variables. They include such examples as the biomass of shrubs, or the concentration of sediments in stream water. Determining the set of management activities to be examined defines the minimum number of variables within the primary models.

Steps 1 and 2 represent an "inward" and "outward" looking approach to model building. In step 1, the resource specialist defines variables to be used to estimate the regional production of their resource. Step 2 is an approach used in Holling's environmental assessment workshops, referred to as "looking outward." This step forces the resource specialist to examine those outside factors that affect the individual resource.

Step 3 represents the consensus across resource areas. Resource interactions vary by the combination of resources considered, the land unit being analyzed, and the spatial and temporal patterning of management within the land unit. Because primary models form the data base for LP models, the assumptions about input data in LP models must be considered. Most commonly, LP models presume production coefficients on a per acre basis, and no interaction between acres. Resource interaction on a per acre basis can be analyzed only for those resources produced on a per acre basis, such as timber and range. Interactions between timber, range, and water require the description of the spatial and temporal patterning of management within a land unit, such as a watershed. Wildlife production may be a function of the temporal and spatial patterning of management across more than one watershed.

Once the resource outputs and mangement activities have been defined, the state variables which must be included in the multiresource models can be defined. If a management activity is to be considered, the variables in the ecosystem which are affected by that activity must be included in the models. Models draw logical consequences only of what was put into them. Step 3 involves a consensus among the resource specialists on these concerns.

Step 4 represents an evaluation by each resource specialist of the types of single resource models. This step is important within each functional area in defining a rigorous approach to quantitatively predict the resource output. This step is important across functional areas in defining a common framework, so that the inputs to these models and the outputs from these models can be used to determine multiresource production in response to management.

In general, simulation models often require more information about the system and data than

statistical models. This information usually consists of quantitative statements about mechanistic relationships and some data which can be used to validate the model. Statistical models, in contrast, require little or no information about mechanistic relationships, but require quantitative data of sufficient quantity and quality to permit statistical relationships to be derived. The intuitive models should be used only where data sufficient to construct either simulation or statistical models are lacking. Two criteria by which to compare alternative models are the amount of uncertainty in their predictions and the accuracy of the predictions.

If possible, extant models should be used. If not possible, then the resource specialist must select a technique to build the model. It is not anticipated that the models in all resource areas would be similar in terms of methodology.

In step 5, the construction of the models would include the model development and the conversion of those models into computer algorithms. The importance of model documentation must be stressed. Documentation provides the mechanism by which models can be efficiently modified and improved.

The exact nature of step 6 is dependent upon the type of model and the original objective for the model. Primary models need to represent the responses of the system to management prescriptions in an acceptable manner. Validation is a procedure by which the responses of the primary models are compared to the responses of the natural resource system under similar conditions. In this analysis, the purpose of the model must be defined, because the criteria by which the performance of the model is to be judged are often dependent upon this purpose (Welch et al. 1981).

Existing Regional Models

Currently, regional level models do not exist in all resource areas. However, some regional models are being developed. Research by Dr. Phillip Tedder, at Oregon State University (OSU), funded by the USDA Forest Service is concentrating on improving the capability to simulate timber management intensification in future national timber supply analyses. The goal is an improved timber inventory projection system that is capable of estimating timber inventories, net annual growth, mortality, removals, and timber supplies by 4 ownership classes, 12 supply regions, and 3 forest types at 10-year intervals, and with specified management regimes, commercial timberland acreages, and prices. This research involves a yield table approach in line with developing a timber age-class based timber inventory projection model for the South, Pacific North-west Westside, and Pacific Southwest, for the 1985 RPA Program Update. A yield table approach is dependent on the availability of underlying timber yield tables for the major timber species in different geographic areas.

Research conducted by Dr. Jeff Klopatek and Thomas Kitchings at Oak Ridge National Laboratory, funded by the USDA Forest Service, focused on obtaining regional estimates of wildlife abundance and distribution. Their approach used the pattern of land cover type and land use class to predict a species population level. County level land use, vegetation data, and animal population data were used to develop a discriminant function for a region which could predict the population level of a species. The vegetation data included the percentage of the land within each county in each cover type and land use class. One regional level discriminant function was developed for each wildlife species of interest. This approach is dependent upon the existence of a regionally consistent data base of variables related to wildlife species abundance and distribution. Once the discriminant function is estimated, the effect of different land use changes on wildlife can be examined as long as the assumptions underlying the analysis do not change.

Regional level models of range forage production do not exist. Forage represents only a part, that is, the available, usable, palatable part of the vegetation that is produced in the ecosystem (Mitchell 1982). Conversion factors to estimate forage from vegetation production are difficult to determine. Vegetation production (primary production) has received much attention in modeling activities. Sharpe (1975) outlined several methods that have been used to determine primary production from existing data sources, such as the RRE data and the CFI data, and existing models, such as in Rosenzweig (1968). Estimating primary production from existing data sources, such as the CFI, assumed that appropriate conversion factors exist. This is not always the case, and assumptions about these conversion factors affect the estimates of regional primary productivity (Sharpe 1975). Regional models are highly influenced by the data used to construct the models, as Sharpe (1975) noted, and Joyce (1981) showed.

CONCLUSIONS

The development of a multiresource framework in which to couch these functional analyses would facilitate the prediction of multiresource outputs. The impacts of resource management intensification would be expressed in the same or similar variables. All resources would be evaluated in response to a commonly defined set of management prescriptions. The development of the multiresource framework and the functional models would also suggest areas where better information is needed to determine resource interactions.

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ECONOMIC EVALUATION OF THE RANGE COMPONENT OF THE RESOURCES PLANNING ACT (RPA) - 1980 UPDATE

John M. Fowler

ABSTRACT: The RPA range program recommends a shift toward productive private holdings to balance fixed supply and increasing demand considerations. The reallocation methodology is theoretically sound, however, the actual resource use valuation is deficient. The suggested reallocation falls under the Theory of the Second Best and is no more defensible than the present allocation.

RECOMMENDED PROGRAM

The range program addressed by the Recommended Renewable Resources Program - 1980 update (USDA 1980) as required by the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) has the following objectives: "designed to provide grazing use where it is ecologically and economically efficient to do so, and adjusted to meet social, political and environmental needs. It covers correction of serious range deterioration while maintaining short-term stability of livestock operators. Minority participation in grazing programs is encouraged." The recommended program (RP) emphasizes efficient production and improvement of rangeland condition. The planners have tackleda very large endeavor in simply assembling the data and feedback in a single manuscript. They are obviously pleased with the thoroughness of their effort and final result as expressed in the following introduction statement. "The program is shaped in part by necessary constraints or personnel ceilings and total budgets, but within these constraints it is balanced, cost-effective, environmentally sound, and responsive to current and projected needs." Not every reviewer has shared the enthusiasm purported by the authors.

The RP provides a range or high and low bounds for output levels, the high bound maintains range use at approximately the current level until 1995. After which, improved rangeland conditions would provide an additional one-half million Animal Unit Months (AUM's) increasing the total to 10.6 million after the year 2000 on National Forest Systems. The low bound would initially decline by .6 million AUM's by 1985, however after 1990, range use would converge to the 10.6 million AUMs attained by the high bound in the year 2000.

Even a cursory examination of the projected National Forest System Program outputs of the RP leaves considerable room for questions. There exists a substantial reversal for the low bound in the period 1991-2000 to jump from 9.4 million AUM's to 10.0 million AUM's while the high bound stays virtually constant from 1983 through the year 2000. This sharp transition seems to be wishful thinking and strongly indicates that the modelers should reevaluate their initial assumptions and their mathematical constructs. If this low bound jump is possible - then the high bound should be able to make at least a strong readjustment during at least one of the time periods.

The overall RPA range program indicates a shift away from federal ranges toward more productive private holdings, within the Forest Service itself the prevailing philosophy was oriented to the intensive margin. Marginal ranges with little opportunity for improvement would be phased out. Several opportunities were presented for the range sector that were deemed necessary to move toward the projected biologic potential of 566 million AUM. Biologic potential must be explained in detail; many laypersons are easily misled by this type of statement. The origin of the number 566 needs documentation or citation. The designated range sector opportunities include: improved grazing systems, range improvements, brush control, poisonous and noxious weed control, insect and disease control, taking advantage of complementary timber growth stages, and intensify research to develop cost-effective methods to revegetate disturbed rangelands.

Intensive margin expansion prevails in the above opportunities or challenges - this orientation can't be allowed to exist wholly as a wish list - but rather the shift to on-the-ground development must be accompanied by an equal budgeting effort. The emphasis on applied research and economic evaluation is a strong movement toward a productive reallocation of manpower and resources if sufficient funds exist to allow investments in long run improvements of significant quantity to capture potential economies of scale.

The goals of the range sector shouldn't be viewed in isolation; if viewed as such, it would be easy to miss some of the flavor and subtle inferences of the RP. It was interesting in some of the statements associated with the wilderness goals: "Current use levels are close to upper limits for some wilderness areas and carrying capacity will be reached in 30 percent of National Forests by 2000 regardless of investments." Interpre-

John M. Fowler is Assistant Professor of Agricultural Economics, Department of Agricultural Economics, New Mexico State University, Las Cruces, New Mexico.

ration, although not 100 percent certain, is that there exists an inference to further shift away from livestock production on wilderness areas. A definite need exists for research to be conducted in the area of impacts of wilderness designation on the costs, returns and organization of ranches.

PUBLISHED COMMENTS

There have been several comments published by producers, groups, user groups, and legislators. The portions of the comments that bear directly upon the range sector are summarized and included to enhance the reader's insight and appreciation of the positions taken by the various factions and the complexity of the issues at hand.

Producer Groups: The National Cattlemen's Association, Public Lands Council, and National Woolgrowers Association had major concerns about the potential for a decrease in National Forest grazing with the low bound of the RP. In addition, the possibility of interspatial shifts in livestock was very apparent. The 1980 RPA update stated that local impacts and social considerations were criteria but the producers contend that the Forest Service (FS) has only paid lip service to the criteria and didn't document how they were used.

Statements were made about the narrow scope of the "cost-efficiency" analysis that basically incorporates only direct monetary benefits to compare against direct costs. Inconsistant valuation measures were used and compared, in addition, a failure to segregate both benefits and costs attributable to non-livestock activities was apparent. The whole attitude was that livestock is competitive and not complementary or even supplementary to other uses. The narrative of the 1980 update of the RPA recognizes the favorable relationships but they aren't included in the valuation calculations. The livestock industry is beginning to fear that its future is limited on public lands.

Conservationists: The conservation position, as expounded by Peter Kirby of the Wilderness Society contends that there is a philosophical difference between public and private lands. Only public lands can provide true wilderness areas and can provide protection for numerous wild and endangered species. Public lands, therefore, should be held to a higher standard. Conservationists have a good deal in common with the livestock industry in that "grazing in some respects enhances the public lands."

Legislators: The Senate forests subcommittee chairman John Melcher (D-Mont.) emphasized that the approach of using a high bound and low bound instead of a specific target, smacks of political expediency. He wants professional foresters to make their best estimates as to what the national forests could and should produce in the next 50 years. Senator Melcher wants an additional goal added to the RP: that 85 percent of the public range be in an "improved forage producing state" by the year 2000. 18 percent of the public range is in poor condition now; the subcommittee wants that reduced to five percent. A resolution is being considered to reject the RPA 1980 update, forcing the administration to start over again.

The National Forest Products Association has also maintained that specific numbers must be set for wood consumer goals. Wilderness Society states that "The non market bounds vary tremendously, from 200 to 300 percent, for timber and range the numbers follow a narrow range. If it comes to a lean year, you know what will be expendable." The range of bounds can also lean to different interpretations by national forest regions when RPA goals are applied to their plans.

RPA GENERALIZED COMMENTS:

Bounds: The high and low bounds impart an initial impression that the resource planners have made a significant move toward recognizing the complexity of resource management. The research community has long advocated the need to move away from discrete absolute numbers toward a more stochastic orientation of at least confidence intervals and expected probability statements. Rather than a discrete number, a mean and standard deviation and other statistical moments yield additional information as to the nature and characteristics of the baseline data. Unfortunately, this wasn't the case or the reason behind the bounds. What the bounds really represent is a high-bound set of goals potentially attainable under a liberal budget and a low-bound set of goals representing the fiscal accountability of the anti-inflationary Executive Office (Krutilla 1981).

Investment Criteria

The relevant economic considerations for the 1980 RPA update aren't concentrated in the area of using appropriate tools and established evaluation criteria. The RPA analyzed investment opportunities via the Net Present Value (NPV) criteria; this is totally acceptable although alternative criteria such as the internal rate of return (IRR), the realizable rate of return (RRR), might also have been used when reinvestment opportunities and expected useful project lives are unequal and vary tremendously across alternatives (Schallau 1981). The area of concern also isn't in the selection of an applicable discount rate; the RPA analyzes outcomes with a range of 4 to 10 percent with 7 1/8 being the standard. These are reasonable approaches and totally defensible if properly applied.

Communication Channels: A basic question related to the overall orientation of the RPA is the concept of an encompassing national policy directive. Assurances have to be made that national policy is not misunderstood by personnel applying the policy in the field. Communication channels between the Washington Office, Regional Offices, Forest Supervisor's Offices and District Offices have not historically been known to be "clear flowing and pristine." Communication breakdowns can occur at every level and particularly at the position of policy application on the districts.

The benefits and costs of the RPA are being both objectively measured and subjectively estimated. Figures are then aggregated for the nation as a whole. In instances where regional and individual forest environmental management policies are the objective, then a proportionate share of the national objective isn't necessarily the ultimate "ticket" to sound management. Flexibility in application is vitally necessary, national policy should be evaluated with an additional criteria of on-the-ground application and acceptability.

Allocation

The fixed resource bases of forest and range land in the National Forests are subjected to a vast and expanding array of demand pressures. There are three basic measures which could potentially alleviate the present and expected future condition of excess demand. First, is the logical escalation of prices for all users groups and types of services provided. Second, is rapidly expending the availability and quality of resource supplies by a prudent investment combination in both the extensive and intensive margins. Lastly, increased awareness of the complementary and supplementary relationships that exist among outputs. This was addressed in the narrative of the RPA text but all output categories were unfortunately evaluated as though they were exclusively single product outputs.

Price level escalation may lead to even further distortions of equity goals due to the existence of many goods and services that are not readily exchanged in the market place. But equity apparently entered only the narrative portion of the RPA and not the actual valuation. This type of superficial "lip service" only confounds the attempt to use economic efficiency and equity as appropriate allocation devices. It is also difficult to comprehend efficient allocation when the concept of marginality either from a production viewpoint or from a utility perspective isn't incorporated or even introduced into the overall scheme of allocation.

In the context of measurement, are both market and non market goods and services being adequately addressed? Compound the measurement question with the failure to account for joint products and multiple benefits; just when you think you understand these questions, throw in the issue of the lack of conceptually valid measures of demand for environmental quality and then tack on the difficulty of empirically justifying associated welfare changes. This is the nature of the problem situation confronting the RPA planners.

Maintaining the policy of good range stewardship may not enjoy the prominent position that it has traditionally enjoyed but on the other hand it should not be treated as the residual use after the allocations to more "vogue" types of uses have occurred. The "last slice of the pie" philosophy must not be allowed to enter the decision making process either explicitly or implicitly.

Actual Use

Several of the presented alternatives of the 1980 RPA update including the low bound of the RP have proposed decreasing animals numbers in at least the short-run situation. This type of action needs additional support; the argument is at least partially valid that comparing objective market values to subjective estimates of non market values is not exactly proper. In addition to the questionable comparison there are problems with the data used in the objective calculation of net present value of livestock grazing. The Forest Service would be hard pressed to be able to come up with the actual number of livestock that are really grazing on public lands. "Actual Use" is not known on many Forest Service or BLM allotments. For any given period, the proxy that is used is the number of animals the permit is issued for minus the non-use. When this type of proxy is used and divergence exists between true numbers and recorded numbers, regression analysis will inaccurately estimate the independent variable coefficient (Freeman 1979). The same improper characterization carries through to correlation coefficients and analysis of variance and many other analysis techniques. Therefore, additional attention should be placed in the arena of rancher-FS range personnel interaction to assure more accurate reporting of true actual use numbers so range condition trend can be correlated to the number of animals actually grazing the allotment.

Adjustments

The most readily apparent 1980 RPA update recommendation for the reallocation process is changing Animal Unit month's (AUM) of grazing. Number changes are a viable adjustment mechanism but should be considered as only one of several options. Alternative courses of action include but aren't limited to changes in the season of use, the type of animal use, and the water density and distribution to expand utilization. Finally, adjust livestock numbers. Concurrent monitoring

must be established to determine long run range condition and trend. It is difficult to advocate and defend reducing livestock numbers when adequate consideration is not given to potential income impacts, changes in wealth position, reduced borrowing capacity and potentially destroying the concept of a "viable economic unit " (Gray and Fowler 1982).

SPECIFIC COMMENTS

Valuation

A key element inherent in the RPA assessment, evaluation, and allocation is the computation of "value" for which the dominant use would be ranked against other uses. As previously mentioned, when deriving a subjective measurement for a non market value, the selection of an appropriate proxy is critical. The 1980 RPA update uses the price of hay as its proxy because it is simple to calculate, the market is well established, and the hay prices are readily available. The formula for computing value of grazing per month is as follows:

Rate =	Animal Weight	x	Hay Price (per ton)	x	Factor
assumed:	1000 pound animal	x	1978 normalized price	x	.12 forage quality

The factor value of .12 reflects a value of poor short grasses or considerable weed growth. This factor was assigned as being most representative for National Forests. This appears to be uniform. After this rate was determined then \$1.74 was subtracted from the rate derived from the formula to account for the services provided by the private sector.

There are several comments that need to be made about this method of analysis. The first obvious problem or least questionable area is the factor used to reflect quality. The factor really translates into simply saying that lush. green, high protein pasture is only worth .22 percent or approximately one-fifth that of baled alfalfa hay. This must be documented if such a relationship does exist. Rather than the quality differential that is purported in the RPA the (.22) rate for lush green high protein pasture might reflect the difference in value between standing forage and baled hay. But this isn't the obvious interpretation.

In addition to the problem of quality, the forage consumption rate differs drastically by animal type and age class. Further, why should just one rate be used, the quality factor should at least have the flexibility for change within forests. There is no basis for aggregating or averaging; the calculation is relatively uncomplicated. If you use state hay prices then at least use individual state quality ratings. Ideally every district should have the factor as a parameter for change in the determination of range value.

Rate Adjustment

What is the basis for the \$1.74 subtracted from the calculated animal rate to account for the service provided for by the private sector. In a study conducted by Gray & Fowler (1982) the average value of landlord services was \$2.14 in New Mexico in 1980 (table 1). The same unit (animal month) was used for the calculation as in the 1980 RPA update. Primary data were derived from 220 questionnaires. Landlord services such as facility maintenance, interest on improvements, checking water and cattle, moving cattle, supplemental feed, and the option of lease changes by lessee. Documentation of the calculation of the \$1.74 is necessary to validate its credibility.

The consequences of livestock adjustments, severity of income change, and wealth impacts resulting from interregional shifts merit additional validity, credibility, and documentation. Potential adjustments must be supported by objectivity and knowledge; and not cursory treatment justified almost wholly on the criteria of ease and simplicity of analysis.

The most serious deficiency of the RPA is the failure to tightly document the annual values of the different dominant uses of the forest land base. Inefficient allocation will obviously occur unless all relevant public and private benefits and costs are incorporated in the analysis and resultant decisions.

Anti-dust

Large documents such as the RPA have the tendency to collect dust, this phenomena isn't due to a peculiar ionic charge but rather due to the bulkiness from the sheer volume of material and a noticeable lack of "robustness" primarily due to the type of material presented. In order to correct such a barrier to common usage at least one controversial issue should be slipped in. In the case of the RPA, many of the alternatives to the RP advocate an initial decrease in livestock numbers leading to an eventual long-run increase in carrying capacity. It is feasible to offer a written guarantee that this indeed will be the end result. The annual value has already been calculated; therefore, compound it, and compensate if not achieved. This approach has its own inherent set of problems and drawbacks but would put teeth into the achievement of specified objectives and goals of the 1980 RPA update.

Coordination

On a more serious note, massive efforts such as the RPA should not be viewed in isolation. Emphasis was placed in the increasingly important projected role of the state and private sector in bridging the gap between demand and supply of forest range related products and yet no mention was made of parallel efforts such as the Resources Conservation Act (RCA). There are obvious problems with inter-agency coordination but the free exchange of technological

Table 1. Gross and net private rangeland lease fees in New Mexico, 1980

Item	Total Amount Reported	Number Reporting Quantity	Unit	Average Amounts Those reporting	All ranchers
	dollars			dollars	dollars
Gross Lease Fee					
Per Animal Month					6.85
Per Acre					1.15
Value of Landlord Services for:					
Facility maintenance					
Per Animal Month	17,625	10,129	AMs	1.74	0.068
Per Acre	21,825	145,550	Acres	0.15	0.001
Interest on improvements[1]					
Per Animal Month	34,659	52,418	AMs	0.66	0.431
Per Acre	25,953	366,568	Acres	0.07	0.028
Checking water and cattle					
Per Animal Month	4,750	990	AMs	4.80	1.056
Per Acre	6,200	77,500	Acres	0.08	0.004
Moving cattle among pastures					
Per Animal Month	1,050	614	AMs	1.71	0.180
Per Acre	600	60,000	Acres	0.01	0.000
Supplement feed and feeding					
Per Animal Month	1,000	599	AMs	1.67	0.045
Per Acre	0	0	Acres	0.00	0.000
Lease change by lessee					
Per Animal Month	3,495	5,445	AMs	0.64	0.356
Per Acre	14,250	47,500	Acre	0.30	0.140
Total Value Landlord Services					
Per Animal Month					2.136
Per Acre					0.173
Net Lease Fee					
Per Animal Month					4.714
Per Acre					0.977

[1] Interest at 12 percent of total investment

innovations and on-the-ground expertise would do wonders to public and private acceptability of recommended programs of both RPA and RCA. Both the RPA and RCA could utilize Land Satellites for detailed assessment work; a standard data base across land management agencies doesn't seem at all inappropriate. There would seem to be a whole range of multiple-resource spinoffs that would then be institutionally as well as economically feasible.

Cost-Effectiveness

The recommended program of the 1980 RPA update has incorporated the tools of economics theory in order to justify intensified investment on rangeland. Only cost-effective improvements would be initiated; unless grazing meets this criteria livestock will be removed. This is an operationally correct procedure if the tool is executed properly. Benefits as well as costs must be accurately assessed. Are private as well as social benefits and costs included in the analysis? Is more than lip-service paid to joint products and multiple-benefits? Are costs based on efficient management? Are the following fiscal considerations included in the analysis of evaluating an improvement practice: initial capital requirements, deferment costs, opportunity cost of money, timing of expected income, costs of operation and maintenance, as well as the expected life of the practice. If the analysis isn't comprehensive and complete then the obvious economic result is Misallocation of Resources.

We in the academic community must provide the leadership, direction and accuracy from applied research results to assure that land management personnel are making decisions based on a knowledge base rather than a position of ignorance.

OVERVIEW

The RPA has taken a large step forward from the first effort in 1975. The documents are more comprehensive, encompassing and have attempted to incorporate positive public comments and feedback. The resource problems addressed are quite intangible and difficult to comprehend. Resource decisions are not clearcut and with escalating competing demands on a fixed resource base there are bound to be issues that don't lend themselves to be resolved to all parties satisfaction.

In conclusion, it is readily apparent that in order to achieve the 1980 RPA update of effective and prudent utilization there should be a gradual shift to an alternative type of livestock on federal and private rangelands. Rather than simply removing cattle from marginal rangelands in the future there should be a gradual transition toward running increased numbers of goats and sheep. This should be done for the following reasons:

A) To take advantage of the complementary relationship existing between cattle and sheep production in terms of increased forage and fiber utilization.

B) To capture and joint-product potential of multiple outputs.

C) To increase the production of natural fabrics versus the energy demanding synthetics because its going to take a lot of wool to pull over the eyes of the general public before the suggested reallocation of the RPA is accepted.

Element (c) is somewhat facetious and should not be interpreted literally. What I'm really advocating is that the RPA process has incorporated applied economics as an important criterion in reallocating scarce resources among competing needs. This is a classic forum for economics, but if incorrectly applied then the reallocation falls under the Theory of the Second Best and is no more or less defensible than the present resource allocation.

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EXTRAMARKET VALUATION FOR RESOURCE ALLOCATION: A CRITIQUE

Ervin G. Schuster and J. Greg Jones

ABSTRACT: An assessment of the relationship between the value of benefits associated with decision alternatives and the values forgone is fundamental to an economic efficiency analysis. Substantial difficulties are introduced when the analysis must integrate market and extramarket values. This paper identifies and discusses several problem areas associated with extramarket valuation--confusion of purpose, product definition, the willingness-to-pay controversy, marginal and average values, the comparability problem, and data problems.

INTRODUCTION

It was with a modest amount of trepidation mixed with a healthy dose of skepticism that we undertook our journey into the world of extramarket valuation--"Extramarketvaluationland." Our mission, were we to accept it, was to determine what the culture was all about, inspect the writings of its scholars, and assess the extent to which what has been done corresponds to what is needed. Ours was to be a scouting trip, a kind of intellectual reconnaissance expedition. Unfamiliar territory it was. Our colleagues warned us to expect "voodoo economics" and the coin of the realm being called "funny money." Undaunted, we began and completed our mission, guided only by the beacon of economic efficiency to better illuminate "truth."

What follows is basically a report on our findings. Time and space necessitate that we share only our major impressions. Specifically, while we encountered public goods valuers, water valuers, cultural valuers, historical valuers, existence and option valuers, and more, the recreation valuers seemed to dominate the landscape and will be the focus of our report. And even with these restrictions, we will not be able to develop full-blown, analytical rationale to support our observations. If our report appears to demean or belittle the rigor and scholarship of any individual or group, that is not our intent; for, indeed, we found an abundance of both rigor and scholarship. Our remarks are organized into six topic areas: confusion of purpose, product definition, value specification, marginal and average values, value comparability, and data problems.

Ervin G. Schuster is a Research Forester and J. Greg Jones is an Economist, both with the Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, Mont.

THE SETTING: A CONFUSION OF PURPOSE?

Upon first setting foot in Extramarketvaluationland, one's initial impression is that the inhabitants share a common vocabulary, but the words do not always have a common, widely accepted meaning.[1] Moreover, one senses that diverse meanings are substantially linked to differences in motivation and background. While this practice can be found elsewhere, we found it to excess.

Consider the term "economic benefits." The Missoulian (a local newspaper) recently carried an article which stated that the economic benefit of big game hunting to Montana was the $386,000 brought into the State by nonresident hunters; others have argued the case of jobs created; others reject the whole notion of valuing recreation on ethical grounds. Some economists have argued for consumer surplus, willingness-to-pay, others for willingness-to-sell, Marshallian demand curves, Hicksian compensated demand curves. We have seen hypothetical fences built around the national forests with imaginary toll gates. We have seen average values, marginal values, average marginals and marginal averages. It's no wonder that they are telling economist jokes in Poland!

This illustrates a major problem which we believe permeates extramarket valuation. There is a lack of agreement as to the conceptual basis underlying "benefits," what should be done to measure them, and why, a confusion of purpose. Willingness-to-sell does not measure the same thing as willingness-to-pay; neither has much if anything to do with income generated and nothing at all to do with production costs. Yet, these and many more techniques can be found in the literature of extramarket valuation over the past two decades. Similarly, when State fish and game managers reject RPA values because they personally know of hunters who spend hundreds if not thousands of dollars to hunt big game, it seems clear that folks are not talking of the same thing. Different purposes or objectives are being served and mixed.

Lest we are to be guilty of what we accuse others of doing, let us attempt to state our perspective as to why extramarket benefits must be and what purpose this serves. Earlier, Ed Fransen discussed the legal/administrative requirement for

[1] We use the "extramarket" throughout this paper. For an excellent discussion of this term and its alternatives (e.g., nonmarket), see Sinden and Worrell (1979).

these analyses. Our rationale is less pragmatic. Rather than pursuing a lengthy discourse on micro-economic theory, let us state our position:

> The purpose of an economic efficiency analysis is to measure or describe the relationship between the value of benefits produced and the value of benefits forgone, pursuant to a particular action(s) or decision alternative(s).

Simple, is it not? We do not use words like maximization or optimization as they imply specific decision rules. We do not even refer to decisionmaking itself. No, the efficiency analysis is a pure thing. Whether and how it's used is an entirely different matter.

We should further embellish this concept. Figure 1 shows a conceptual model of a situation wherein some type of extramarket commodity could be produced at various levels via increasingly costly alternatives (A_0 - A_3). An economic efficiency analysis would develop the information base for constructing figure 1.

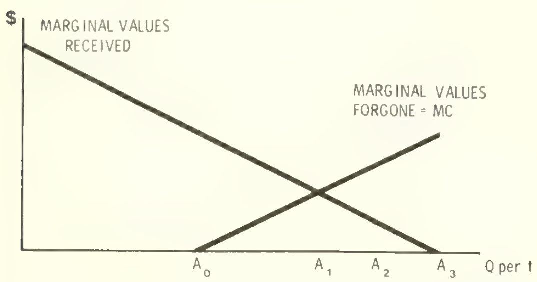

Figure 1.--Hypothetical decision alternative values.

Several points should be made. First, the relationships shown pertain to a specific time interval (t) (e.g., per season, year, or decade) which must be, but too frequently is not, made explicit. While the curves may shift over time, the process of discounting can easily make adjustments; in fact, figure 1 could be interpreted in present value terms. Second, the relationships pertain to a specific market area. Value relationships of importance are at the market level, not that of the individual consumer. Heartless as it may seem, the individual is largely irrelevant, gaining relevancy only by participation in the market. Finally, the curves reflect both decreasing marginal productivity in production and downward sloping demand, characteristic of demand forced by firms operating in imperfectly competitive markets. We have in mind a set of consequential alternatives of a program nature, not small-scale projects that have no effect on market outcomes.

The valuation of extramarket benefits is rooted in the need to assess the efficiency of resource use. This should be clearly distinguished from analyses of the effects of resource use on individuals and local or regional economies.

PRODUCT DEFINITION

The problems associated with extramarket valuation go deeper than merely a lack of shared purpose. We found inconsistency, if not rampant disagreement, as to how the quantity axis should be labeled. That is: what product is being produced? This problem is particularly important because it inhibits communication and diverts research resources into diverse, sometimes seemingly fruitless, topic areas. We will discuss two dimensions of this problem.

First, resource economists and resource managers tend to have different perspectives of the product. While the economist typically views the product from the standpoint of the consumer and the market, the manager frequently views it in terms of direct management output--critters (antelope or trout) or facilities (campgrounds or boat launches). This has caused communication problems, for the differences in product perception frequently reflect a difference in personal or professional perspective. These perspectives have been described variously but fundamentally as "ecocentric" and "homocentric" points of view. In the case of the USDA Forest Service, the homocentric view seems to prevail, at least in terms of official policy. Directives and guidelines pertaining to RPA and forest planning have defined a set of "standard outputs." The outputs of antelope management may be measured in recreation visitor days (RVDs) of big game hunting, steelhead habitat improvements in RVDs of anadromous fishing, campground establishment in RVDs of developed recreation. The upshot of this has been a marked refocus of extramarket value research; studies of a decade or more ago that may have focused on the value of a goose now focus on goose hunting.

Although agency policies may well simplify some problems of what to measure, they cannot overcome inherent ideological differences. Those believing that big game populations are inherently valuable will continue to reject the notion that worth takes on meaning only in the context of human tastes and preferences.

The second dimension to the product definition problem may be termed the "site versus experience" issue. It concerns which recreational value ought to be measured. At issue is whether the appropriate value is that of the entire recreation experience, or the value of the recreation opportunity afforded at the site itself. If it is the former, then one must value the recreation experience in its entirety--anticipation, travel, participation, and recollection (Clawson and Knetsch 1966). If the latter is the appropriate perspective, then only the value attributable to the site should be included. Both can be measured in terms of value per recreation visitor day. But the magnitude of per day value for a given type of recreation is likely to be quite different. Thus, whether or not an estimate of value appears reasonable depends upon which perspective is being used.

There would not seem to be any general conclusion as to which perspective is more appropriate. It depends on who you are, your vantage point. The governor of a State probably should look at recreation quite differently than would a district ranger. As for land management agencies, the recreation site or space is the only factor input that can be provided to the recreationist; the other input factors such as travel, gear, lodging, time, etc., are provided elsewhere, and the recreationist personally "manufactures" the experience.

Resource economists now seem to agree that the value for use of the "recreation site" is the appropriate focus for land-managing organizations providing the site only, if an economic efficiency analysis is being performed. The meaning of "site" varies with the type of recreation and the purpose of the analysis. Site may refer to a campground, a national forest, or a region, depending on the scope of analysis. (Note, later discussion will present in more detail the logic underlying why the value of the site appears to be the appropriate perspective for land managing organizations.)

The choice between site versus experience is so critically important to extramarket valuation that a task force on wildlife and fish values adopted the convention "if one envisions a fence around National Forest lands with a gate..." in order to preclude task force members from mixing approaches and confusing debate.[2] Failure to adequately define or recognize alternative perspectives is rampant in the extramarket valuation literature. The bulk of the studies we inspected seems to imply products corresponding to or equivalent to the experience level. Accordingly, it is difficult to infer site-level values from experience-level studies.

VALUE SPECIFICATION: THE WTP CONTROVERSY

Several years ago in a Journal of Forestry article, Dwyer and Bowes (1979) stated that the theory and procedures for estimating willingness-to-pay (WTP) have been developed sufficiently and should be applied to estimate benefits in appraisals of recreation alternatives. That article was accompanied by a comment (Dyer and Hof 1979) that stated that Dwyer and Bowes underestimate the complexity of applying WTP theory and that outlined some of the difficulties involved. The above articles generated a number of subsequent responses, published in the January 1980 journal. Remaining discussion was concerned with issues regarding operational estimation of WTP, such as the appropriateness of assumptions required for estimating recreation demand functions by the travel cost method.

[2]USDA Forest Service. Defining recreational values dependent on wildlife and fish to be used in regional and forest land and resource management planning. Unpublished report of the Wildlife and Fish Values Task Force, USDA Forest Service, WO; 1980.

The WTP approach has long been controversial. It seems to elicit only absolute reactions--absolute agreement, absolute disagreement, or absolute confusion. Although the debate in natural resource circles has not been nearly as eloquent, or as rigorous as the literary dialog between the likes of Hicks and Samuelson, it does exist. In the natural research arena, the debate seems to have centered around three topics: (a) can it be measured; and if so, (b) is it equivalent or comparable to other value measurements; and (c) is it a legitimate measure of value?

The theory underlying willingness-to-pay as a measure of benefits is well developed and widely discussed in connection with extramarket valuation (Mishan 1971). WTP is a dollar measure of the value people place on goods and services. It is defined as the maximum a consumer would pay for a specific amount of a commodity rather than go without. (Note: Unless marginals or averages are specifically indicated, WTP will mean total WPT, as in the literature.) Willingness-to-pay at the site includes any fees actually paid for use of the site, plus any additional amount users would pay over and above this amount. The "additional amount" should immediately be recognized as corresponding to consumer's surplus (CS). When use of a recreation site is provided to the recreationist without charge, consumer's surplus and willingness to pay are the same.[3]

WTP at the site (for a specific quantity or quantity increment during a time interval) is related to the total value of experience (again anticipation, actual participation, recollection, and travel to and from the site) in the following way:

$$\text{WTP for use of a site} = \text{WTP for the total experience} - \text{Transaction costs}$$

Transaction costs include dollars spent for goods and services associated with the recreation experience other than the site; e.g., gasoline, food, equipment, and vendor services. Money spent for these items partially reflects their economic demand. Including these dollars in the demand for the recreation site would constitute double-counting.

[3]The economic concept of willingness-to-pay has a rigorous, technical meaning that may be inconsistent with its intuitive, lay interpretation. While the economist envisions income constraints, marginal utility trade-offs, and more, the intuitive perception probably reflects tastes and preferences only, unconstrained by income and trade-off realities. In fact, these realities may be viewed as contrary to the idea of willingness-to-pay. Interpretation differences may result in communication problems.

Assume a production situation rather like that previously shown by the increasingly costly management alternatives in figure 1. Given the desire to perform an economic efficiency analysis, for illustrative purposes let us choose consumer's surplus as the measure of benefit--consumer's willingness-to- pay. All we need is an actual demand curve from which to measure consumer's surplus.

But not just any demand curve will do. Only a Hicks (income) compensated demand curve (HCDC) will be sufficient. In his "Revision of Demand Theory" (1956), J. R. Hicks points out the inadequacies in Marshall's approach to consumer's surplus, corrects previous statements, and more fully elaborates four approaches to consumers surplus. Hicks argued that the Marshallian demand curve (MDC) views the issue from the wrong perspective, when willingness-to-pay is at issue. While the MDC is based on a price-to-quantity approach where the consumer faces a price and chooses a quantity, Hicks advocated the quantity-to-price approach where the consumer faces an all or nothing choice for a fixed quantity and must specify the price or amount that will be paid. The area under a MDC misrepresents this amount because along it, the consumer's real income is changing, increasing for price decreases and decreasing for price increases. Both the income and substitution effects operate along a MDC. Under the MDC, nominal income is held constant; under the HCDC real income is held constant.

Hicks developed several consumer's surplus-oriented concepts widely used in extramarket valuation. Their presentation is best made through indifference curve analysis, as demonstrated particularly well by Currie, Murphy et al. (1971). Paraquoting Hicks, they define two of these concepts of special interest to us:

-- "Compensating variation" is the amount of compensation, paid or received, that will leave the consumer in his initial welfare position following the change in price if he is free to buy any quantity of the commodity at the new price."

-- "Equivalent variation" is the amount of compensation, paid or received, that will leave the consumer in his subsequent welfare position in the absence of the price change if he is free to buy any quantity of the commodity at the old price."

Randall (ca.1979) describes the Hicksian compensating and equivalent measures of consumer's surplus as differing with respect to the reference point:

> The compensating measure, by using the initial welfare level as the reference level, measures the welfare impact of changes as if the individual had a right to his initial level of welfare...The equivalent measure, by treating the subsequent welfare level as the reference level, treats the individual as if he had only a right to his subsequent level of welfare....

Hicks' compensating measure and the correspondin compensated demand curve have become known a "willingness-to-pay" while the equivalent measur is known as "willingness-to-sell."[4]

There appears to be little doubt but that i consumer's surplus is to be used, it must b computed from a HCDC. A MDC is, in general wrong; it will, in general, overstate th magnitude of willingness-to-pay and henc consumer's surplus. Modifying figure 1, figure now shows the same type of information but wit the HCDC and the MDC shown. Real income alon HCDC is held constant and equals the real incom on the MDC when prices P_o.

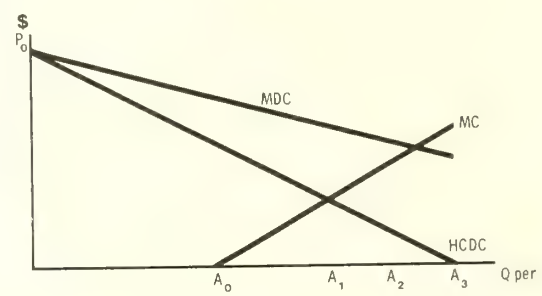

Figure 2.--Marshallian (MDC) and Hicksian (HCDC) demand curves.

[4] We confess to concern regarding the appropriateness of public agencies using the concept of willingness-to-sell. The word "right" frequently appears in conjunction with WTS. For example, Randall (ca.1979) describes the equivalent measure "as if the individual had a right to...as if he had a choice of keeping what he has or voluntarily trading for changes." Normally, producers maintain (property) rights to output until the rights are transferred to the consumer, the consumer having no prior rights in the product. Sanctioning the notion of recreationist's WTS may entail legal/policy implications.

As can be seen for any price on the vertical axis, the Marshallian measure of consumer's surplus will exceed that of the Hicksian measure. Unlike the MDC, the HCDC shows the maximum a consumer would be willing-to-pay for an additional unit of the commodity, assuming the maximum amount were already paid for each preceding unit purchased, real income constraint (Currie et al. 1971).

The reason that the forgoing is important to extramarket valuation is that, as difficult as they are to estimate, only the MDC is observable. While it may be correct, the HCDC is conceptual. So the question is: how far are they apart and what circumstances control their discrepancy? This much can be said categorically: if demand for the commodity in question is associated with zero income effect, then the HCDC and the MDC are one and the same. The demand curve is then a reflection of the substitution effect only. Furthermore, as the income effect becomes smaller, the MDC will merge into the HCDC. So it is important to be able to assess the size of the income effect in order to judge how closely the MDC approximates the HCDC.[5]

Enter Willig (1976). In his famous article, "Consumer's Surplus Without Apology," Willig identified the circumstances under which observed consumers' surplus can be used to estimate the unobservable, theoretically correct, measures. Willig's argument goes as follows: if the income effect is zero, then willingness-to-pay (compensating variation) will equal willingness-to-sell (equivalent variation) and so to estimate how closely one approximates the other is tantamount to estimating the significance of the income effect. Willig's formulae require specification of income elasticity and the consumer's income level to estimate the importance of the income effect. Apparently expecting approximation errors in the magnitude of 2.75 percent, Dwyer et al. (1977) concluded that the MDC adequately approximates HCDC. Lending additional support to this contention, Binkley (1980) writes that "Fortunately, Willig...has offered recreation analysts some relief...(showing)...that if income elasticity is small...and consumer's surplus relative to total income..., then the area under the ordinary (Marshallian) demand curve is a good approximation to the theoretically exact measures of welfare." Dwyer et al. (1977) concluded that "these conditions are almost always met for recreation output of resource management alternatives."

The implications of this line of reasoning are far reaching: willingness-to-sell estimates (approximately) willingness-to-pay (also vice versa), and either can be used to estimate (approximately) consumer's surplus. Accordingly, this justifies (it is argued) using ordinary (Marshallian) demand, such as that estimated by the travel cost method, to estimate willingness-to-pay for recreation outputs.

That a potential problem exists should probably have been detected early-on. The king-pin concept in all of this is the income effect--it must be zero (or approximately so). This is a pretty heavy-duty contention. Analytically, a zero income effect means indifference curves are vertically parallel. The equilibrium quantity of the commodity in question does not change as the price-ratio line is shifted parallel, reflecting increases and decreases in income. Interestingly, consumption is independent of income. Necessarily then, income elasticity of demand for the commodity is zero. You might then expect to find as many rich folks shooting pool as poor folks and as many poor folks shooting the rapids as the rich. Did not Clawson discuss income along with population, leisure, and transportation as factors that have underlain demand for outdoor recreation?

Empirical evidence, however, seems to conflict with the notion that the income effect is approximately zero. In Davis' (1963) study of willingness to pay for deer hunting, household income appeared as a significant variable in multiple regression models. In an article evaluating the required correspondence between willingness-to-pay (WTP) and -sell (WTS) as revealed in previous empirical studies, Gordon and Knetsch (1979) highlighted three studies in which all found WTS far exceeded WTP:

	Topic	Measure	Amount	Difference
			dollars	percent
I	Waterfowl hunting	WTP	247	
		WTS	1,044	423
II	Local fishing pier	WTP	43	
		WTS	120	279
	Postal delivery	WTP	22	
		WTS	93	423
III	BC fishing	WTP	35	
		WTS	700	2,000

[5]We should note that even a zero income effect does not alleviate concern over double-counting of values. The argument goes as follows. Consumers exhaust income either by spending or saving. While consumer's surplus may represent the value of benefits received without payment, these surpluses are in fact spent elsewhere. The "surplus" is already accounted for in the demand for other goods and services. That is, consumer's surplus values for commodity X are (at least partially) reflected in consumption and payments for commodity Y or in the level of savings. Were it not for these "free" benefits, consumption of commodity Y (and probably X) or the level of savings would be diminished. Since payments for commodity Y and for saving are already being "counted" elsewhere, to additionally count consumer's surplus values is to double-count. The HCDC tends to diminish the double-counting issue.

The large discrepancies between WTP and WTS led them to conclude a "caution" to the ready assumption that estimates of WTS can be approximated by WTP.[6] Third, in a study of goose hunting permits, Bishop and Heberlein (1979) estimated goose hunting permits hypothetical WTP at \$21 while WTS was estimated at \$101, a 481 percent difference. In recent research continuing the line of investigation by Gordon and Knetsch (1979), Knetsch and Sinden conducted a series of five experimental lotteries involving real money and real people. They found that in four of the five experiments, WTS was (statistically) significantly higher than WTP (in the one reported result WTP was \$0.81 while WTS was \$2.31, a 285 percent difference).[7] One conclusion reached was that the two measures of economic value are not equivalent.[8] We know of no empirical studies in which WTS and WTP appeared to be approximately equal.

[6]Empirical studies of WTS commonly reject extremely large answers "outlyers." This practice can scarcely be condoned on theoretical grounds. For as Hicks (1956) said:

> even in the case of a necessary commodity, the compensating surplus (WTP) is limited by income; but the equivalent surplus (WTS) may be practically infinite. (Parenthetical words added.)

Theoretically put, indifference curves need not intersect either axis.

[7]Knetsch, J. L. and J. A. Sinden. Willingness to pay and compensation demanded: experimental evidence of an unexpected disparity in measures of value. Unpub. manuscript. Simon Fraser Univ., Dept. Econ., Burnaby, B.C.; 1982. 22 p.

[8]Let us speculate on the cause of these large discrepancies beyond those suggested by Gordon and Knetsch (1979). An erroneously conceived "income" may be the culprit. While economic theory may identify "income" as important to consumer behavior, it is silent on which measure of income should be used. Should it be household or per capita, before taxes or after, including or excluding nondiscretionary payments (such as home mortgage, car payments, or college costs?). We suggest that if "income" is interpreted as "discretionary, after-tax income" the likelihood of substantial income effect increases appreciably. "Apparently" modest payments for recreation commodities do not then represent insignificant expenditures.

Where does the preceding dialog leave extramarke valuations? In shambles, we think. If extra market benefits are to be measured by consumer' surplus as a reflection of what consumers ar willing-to-pay. And, if consumer's surplu measured under a Hicksian (income) compensate demand curve is acknowledged to be correct, bu immeasurable. Further, if the consumer's surplu under the measurable Marshallian demand curve ca approximate the Hicksian measure, but only unde certain conditions (e.g., approximately zer income effect). And if the approximation i acceptable, based on expected errors in the orde of 2.75 percent. But empirical studies woul suggest errors in the hundreds and thousands percent. Then, the income effect cannot be ignored the MDC is not (approximately) coincident wit the HCDC, Marshallian consumer's surplus doe not approximate Hicksian, and therefore th desired measure of welfare has not, in fact, bee measured. Ergo, you are in shambles.

MARGINAL VALUE VERSUS AVERAGE VALUE

Estimation of WTP can frequently be hampered b lack of a usable demand relationship, Marshallia as well as Hicksian. One way to estimate WT when a demand function is not available is t multiply the change in quantity by the average o the before and after price (U.S. Water Resource Council 1979). This concept applied to a hypothetical outdoor recreation activity is illustrated in figure 3. P_o is the amount consumers

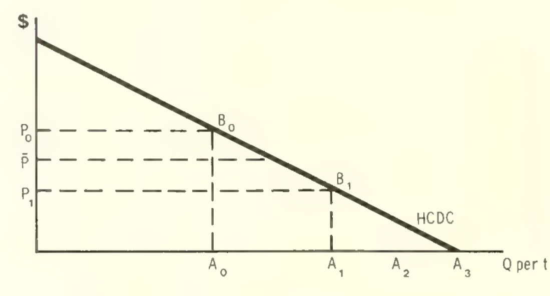

Figure 3.--WTP based on $\bar{P}$.

would pay for the last unit of output at A_o and P_1 is what they would pay for the last unit at A_1. WTP for the increment in output from A_o to A_1, area $A_o B_o B_1 A_1$, is estimated by multiplying $\bar{P}$ (the average) times the change in quantity ($A_1 - A_o$). This procedure is designed to estimate WTP for discrete changes in output expected from project alternatives and is a conceptually correct approximation for that purpose. In fact, the approximation is exact if the demand curve is linear.

This approach goes awry, however, when average WTP is applied as if it were price, a marginal WTP, in an economic analysis of a firm operating in a competitive market. Consider figure 4 where A_1 is the optimal level of output. Assume that $\bar{P}$

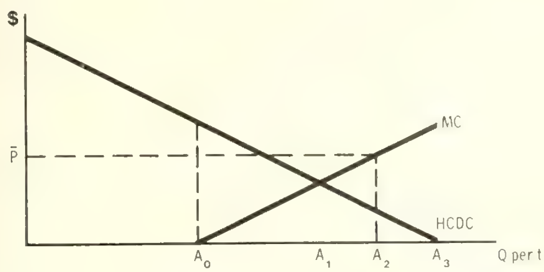

Figure 4.--Decision choice using $\bar{P}$.

represents the average WTP over some increment in quantity. The increment could start anywhere from zero to A_2. MC is the marginal cost of increasing recreation opportunities. Net benefit (profit for a private firm) equals price times quantity minus total costs. Net benefit is maximized at the quantity where price, in this case $\bar{P}$, equals MC. This occurs at a quantity of A_2.

The discrepancy between the optimal level of production identified by this approach (A_2) and the actual optimal (A_1) arises from the fact that $\bar{P}$ (or any average for that matter) corresponds to a specific level of output only. If the output level is increased, average WTP must decrease, assuming a downward-sloping demand. This relationship is ignored when average WTP is treated as if it is a price.[9]

Although this pitfall may seem apparent on the surface, it may be rather easy to fall into in practice. Applying WTP concepts to estimate benefit value is not easy. Correctly applied, it requires estimation of WTP at the margin for a number of output levels, if a marginal analysis comparing WTP for an additional unit with the cost of providing that unit is to be done. If the average WTP approach is used, average WTP must be estimated for various levels of output (as pointed out above) to have an unbiased estimate of benefits. In view of these difficulties, it may often be necessary, given time and budget constraints, to simplify an analysis by treating average WTP as a price and proceeding. The danger of this approach is that it can substantially overestimate benefits. It is in the context of average WTP in figure 4 that average values (whether based on WRC unit day values, average consumer's surplus from a travel cost model, or mean willingness-to-pay values from a questionnaire) used in analyses must be evaluated. We consider the practice of interchanging total, average, and marginal values to be a major problem in application of extramarket values. Interestingly, many opportunities to criticize extramarket values would be eliminated if marginal values were used exclusively.

[9]There is a certain degree of irrelevancy in these analyses. For even if the HCDC were correctly specified, A_1 were the alternative chosen, and if no price were charged, recreationists would still participate at a level corresponding to alternative A_3 or beyond, wherever the MDC intersects the quantity axis. Without a price charged, recreationists will always expand participation to where the marginal value (WTP) is zero.

VALUE COMPARABILITY: THE EVENHANDEDNESS ISSUE

We doubt any single issue has plagued extramarket valuation as much as has the issue of comparability. It's neither a trivial issue nor a new issue. Comparability and consistency come into focus when market and extramarket inputs, outputs, and values are merged. Dyer and Hof (1979, 1980) pointed out that if WTP procedures are used to value recreation, then in order to maintain consistency, they should be applied to all outputs included in the analysis. A decade earlier, Beardsley (1971) argued that values incorporated in resource allocation models must, among other things, be comparable to all other measures of value in the model. During the preceding decade, Wennergren (1964) said: "Unfortunately, most public recreation is not market-priced and thus estimates of comparable value are difficult. But it is this lack of conventional market pricing and not the associated esthetic values that complicates the valuation process." We are convinced that to assert "lingering doubt" and "endemic skepticism" exists would not overstate the type of reservation felt by our colleagues.

There are at least two sides to the comparability coin. The first deals with comparability among output values. This aspect has certainly received the most attention. In 1971, Beardsley said that when compared to consumer's surplus measures, "market-price values for resource uses do not include consumer's surplus values and the two cannot be legitimately compared...." Binkley (1980) and by implication Bowes and Dwyer (1980) argued that it is not necessarily inconsistent to value recreation by WTP procedures, while using market value approaches for other commodities. Both views are correct, under certain conditions.

The central issue boils down to the slope of the demand curves in question. When demand for a commodity is horizontal (i.e., firm in a perfectly competitive industry), market price times quantity is the same as WTP since consumer's surplus in this instance is nonexistent. Some may view the market in which forest and rangeland commodities are exchanged to be sufficiently large (possibly national in scope) such that resource decisions do not influence quantities sufficiently to affect price. Therefore, the demand for these commodities is flat over relevant potential changes in quantity. When this condition holds, market prices contain consumer's surplus, but it is zero.[10]

Alternatively, it can be argued that while consumer goods produced from forest commodities (e.g., lumber, paper, and meat) are often sold nationwide (or at least over wide geographic areas) at common prices, the forest commodities themselves from which these products are produced (e.g., standing timber, and forage) typically are not exchanged nationally or even over wide geographic areas. Land management organizations most commonly produce and market forest commodities, not consumer goods. It appears that markets for many forest commodities are limited to much smaller geographic areas than what some have suggested. They are perhaps more aptly described as local or regional markets. In such instances, consistency is maintained only when WTP procedures are used to place values on these commodities as well as recreation. As Dyer and Hof (1980) suggest, this presents a formidable task.

The other side to the comparability coin involves inputs. This topic has scarcely been discussed in the extramarket valuation literature. We earlier set a rather modest goal for an economic efficiency analysis--a comparison of the values produced to the values forgone. As it is critically important to measure all benefits by equivalent standards, so it is that costs be measured by the same standard as benefits. After all, they both may go into a present net worth calculation. But are they equivalent? Two aspects seem important.

The first deals with actual, out-of-pocket costs, expenditures to secure the services factor inputs. Dorfman (1972, p. 75) indicates:

> In monetary terms, the opportunity cost of producing anything is the <u>value</u> of the resources that it absorbs, because that <u>value</u> reflects the usefulness of those resources in other employments. (Emphasis added.)

Conceptually, the price paid for a resource measures its productive value in other uses--<u>at the margin of equilibrium</u>. Trescott (1970, pg. 284) puts it this way:

> In long-run competitive equilibrium, the <u>price</u> of each product tends to equal both the cost of the resources used in producing the marginal unit and also <u>the value of other products which could have been produced with the same quantity of resources</u>. We know that the price of each product tends to equal its marginal cost. Remember also that each input must be paid an amount equal to the value of its marginal product in the rest of the economy. Combining these ideas yields the idea that the marginal cost of one product measures the value of the product that one could have obtained with the same resources. (Emphasis added.)

Factor prices represent alternative values forgone, at the margin. It hardly seems comparable for an organization to measure some output values (benefits) on a WTP basis while inputs (costs) are assigned marginal, equilibrium values.

The second aspect of factor cost concerns time. Discounting is frequently applied in resource allocation analyses, since decisions often involve committing resources and receiving benefits over relatively long periods of time. There appears to be general agreement that the discount rate used in analyzing investments in the public sector should be based on the opportunity cost of capital in the private sector (Row et al. 1981). That is, it should measure the net value forgone in the private sector (in terms of an earning rate) to provide capital for public investments. Furthermore, as Row and others argued in recommending a 4 percent rather than a 10 percent discount rate, the rate should be a marginal rate rather than a higher, average rate.

To maintain consistency in measurement, it is also important that forgone benefits in the private sector, reflected by the opportunity cost of capital, be measured in a manner consistent with the benefits in an analysis. If they are not measured by the same yardstick, the trade-offs between public and private investments are incorrectly specified. It appears that when WTP is used to value outputs in public resource allocation analysis, a different yardstick may in fact be used. Benefits (actually receipts) underlying the private sector earning rates are based on revenue earned by producers, price-times-quantity relationships. Consistency is maintained only under one or more of the following conditions:

[10]We note the irony in this procedure. If for a given market area, a given industry could be organized alternatively as perfectly competitive and as a monopoly, with equilibria in place, then we could measure positive consumer's surplus with the monopoly and none with the competitive industry. The later situation results because each of the competitive firms has a horizontal demand curve with no consumer's surplus.

1. If all producers in the private sector, on which the opportunity cost of capital is based, are perfectly discriminating monopolists, such that all the consumer's surplus for the outputs that could have been produced would have been captured by the producers (i.e., no remaining consumer's surplus).

2. If the outputs that could have been produced in the private sector (with the dollars required by the public alternatives under consideration) would not have influenced any prices, such that consumer's surplus equals zero.

3. If the change in outputs associated with the public alternatives under consideration in an analysis would not affect WTP at the margin (WTP for each additional unit produced is constant) for any of the commodities that would be produced.

There is no guarantee that any of these conditions would be present. In fact, in view of the relatively large amount of resources associated with some land management decisions (e.g., the budgets associated with national forest plans), one would expect these conditions to rarely hold. In their absence, benefits that could be produced by public investments are overvalued, relative to benefits that could be produced in the private sector (since total WTP would be greater than market price times quantity). This tends to promote overallocation of resources to public projects, because it exaggerates present net values.

DATA PROBLEMS

Apart from the conceptual difficulties in extramarket valuation, there are some rather substantial empirical problems as well. Not intending a comprehensive review, we will highlight what we consider as major problems in three areas: output measurements, market-specific information, and contemporary techniques.

First, in order to determine total value, some measure of value must be applied to output quantity. Yet, the analytical status of mensurational techniques to estimate (predict or project?) levels of extramarket outputs could best be described as pathetic, approaching nonexistent. This is indeed unfortunate because it lends credence to those who contend that value estimates do not need to be precise because the output estimates are so unreliable. We expect that confidence intervals constructed around output "estimates" would generally include zero. But the problem is not just that of estimating RVDs per se. The problem is translating management activities into extramarket outputs (Batie and Shakman 1979). For example, a wildlife habitat improvement project must be translated into habitat characteristics. The changed habitat must be translated into changed wildlife populations, and that must be ultimately linked to RVDs of big game hunting. Right now, the most widely used technique by which this is done is called BPJ--best professional judgment.

Second, the need for extramarket value information totally overwhelms available empirical research, rather like the Sahara overwhelms the oases. If each of the 174 national forests and grasslands produced only four types of recreation--developed, dispersed, game-oriented, and fish-oriented--almost 700 demand models would be needed to quantify a point in time! Only a few dozen models have been produced over all time. Not surprisingly then, study results pertaining to a certain place for a specific point in time have been extrapolated thousands of miles, and over decades of time. One can only speculate whether the deer hunters in Montana in 1982 are like the deer hunters in Maine, two decades earlier.

Third, we feel compelled to briefly comment on valuation techniques currently in use. Since thorough discussions of these techniques are available elsewhere (Dwyer, Kelley, and Bowes 1977; Dwyer 1980; Kaiser and Marchetta ca.1981; and Johnson, King, and Hay ca.1979), we shall confine our remarks to what we feel are the most substantial concerns, apart from those already aired. Following the format of the U.S. Water Resources Council (1979) we will consider Unit Day Values (UDV), Travel Cost Method (TCM) values, and Contingent Value Method (CVM) values.

1. UDV: It is difficult to add to the thorough discrediting of Unit Day Values by other analysts, ranging from Clawson and Knetsch (1966) to Dwyer, Kelley, and Bowes (1977) to Dwyer (1980). The listing below shows the ranges of values per (general and specialized) recreation day published for various years by the U.S. Water Resources Council:

Year	General	Specialized
1962	$0.50 - 1.50	$2.00 - 6.00
1973	0.75 - 2.25	3.00 - 9.00
1979	1.07 - 3.22	4.29 - 12.87

Apparently, these values were originally conceived of as market clearing prices, adjusted in later years for inflation. Mechanical procedures have been devised to convert UDVs to values per RVD and to specific types of recreation. UDVs are commonly used as was $\bar{P}$ in figure 4, although they have no necessary analytical relationship to any curve shown. While there is no empirical or theoretical basis for these values, they undoubtedly enjoy the most widespread usage.

2. TCM: the travel cost method uses actual expenditures (measured or assumed) as a basis for specifying a demand curve for a site. It is a Marshallian-type curve, corresponding to the consumer's surplus area associated with the commodities purchased. The TCM always reflects benefits for the whole experience rather than site use alone. Since recreationists commonly pay less than WTP for nonsite inputs, some nothing, apportionment of (residual) consumer's surplus to the site is arbitrary. Methodological advances in terms of substitutes and travel time seem both promising and important. The travel time adjustment is most controversial, devolving down to questions of whether or not there is an opportunity cost of time for recreation and if so, how to measure it and reflect it analytically. In a recent study, Bishop and Heberlein (1979) found that the TCM estimated value changed by about 400 percent depending on choice of assumption concerning time values.

3. CVM: The contingent value method relies on a question and answer format, sometimes a questionnaire, sometimes a "bidding" game. This method suffers from SQC--severely questionable credibility. It conjures recollections of television game shows. The credibility issue has two dimensions. First, the question. It is difficult, maybe impossible, to formulate a stimulus (question) that will elicit an unambiguous response (answer) measurement on the complex variable being estimated. Any one inspecting the technical definition of Hicksian compensated and equivalent variations will surely see the point. Anyone who has written a simple straightforward examination question and is later totally amazed by the number of different interpretations given by students, will also appreciate this point. Second, the answer. People do not necessarily lie, but neither do they necessarily say what they mean or do what they say. Hancock (1973) found recreationists' behavior appreciably inconsistent with stated intentions. Apart from strategic bidding and other biases (Schulze and others 1981), people may not know of their feelings. Bishop and Heberlein (1979) found that the hypothetical willingness-to-sell value was almost twice that of actual. Driver and Harris (ca.1981) have suggested the possibility of a "lack-of-experience-in-thinking-that-way" problem. In short, it takes a real act of faith to put much credence in CVM results.

DISCUSSION

We close with a remark about the intellectual legal system we found. It is extended well beyond the normal "innocent until proven guilty" concept to which we were accustomed. There are two standards for "burden of proof." Not only must the plaintiff prove a defendant idea guilty of being "fallacious," beyond a reasonable doubt, but he must also prove that the fallaciousness makes any ultimate difference. The technical term for this is quid importat, roughly translated, "so what." This latter standard is very disarming to prosecutors. Based on convictions, we not surprisingly found a very low crime rate.

This then concludes the report of our travels in Extramarketvaluationland. We saw many wondrous sights. In fact, our journey was frequently interrupted by occasions to wonder. On one occasion, as we stood peering into a pool of ideas, incapable of perceiving form and substance, an old sage winked and lent us comfort by saying "not to worry, pilgrims, there's less there than meets the eye."

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RANGE ECONOMICS IN FOREST LEVEL PLANNING

Robert G. Williams

ABSTRACT: Planners on the Targhee National Forest have recently completed a land management plan for the Forest as required by the 1976 National Forest Management Act (NFMA). Regulations implementing NFMA specify several areas where economic analysis must occur. Analysts on the Targhee were able to accurately estimate the capability of the Forest to produce forage and the associated cost of production. However, the Targhee and most other Forests in the Intermountain Region do not have the capability to accurately project demand and the associated price-quantity relationships for forage.

Both the regulations implementing the 1976 National Forest Management Act (NFMA)[1] and subsequent direction in the Forest Service Manual[2] specify several areas where economics is to be considered in Land Management Planning. Some of the more obvious examples include direction to:

1. Develop a supply analysis for various goods and services.

2. Develop projections of demand including price-quantity relationships.

3. Prepare a comparative analysis of alternatives that examines, among other things, economic efficiency and distributional effects.

More recently, revisions to the NFMA regulations[3] provide additional emphasis on economic considerations in Forest land management planning. Some specific examples include:

1. Identifying the mix of resources which will maximize present net value.

2. Establishing the present net value assessment as the beginning point for formulating alternative.

3. Identifying the alternative that comes nearest to maximizing public benefits.

At this point in time, it is therefore appropriate to examine how well the economic analysis was done in some early Forest plans - where we were weak, where we were strong, and where we could use some help from the Research arm of the Forest Service.

Since the Forest I work on, the Targhee, recently completed a Proposed Land Management Plan, I will draw on our experience looking primarily at the range resource.

First a quick orientation to the Targhee. The Forest is located in southeastern Idaho and western Wyoming. The Continental Divide between Idaho and Montana forms much of the northern boundary; the Targhee has boundaries common to both Grand Teton and Yellowstone National Parks. The Forest Supervisor's Office is located in St. Anthony, 40 miles north of Idaho Falls.

The Targhee is not noted as a "range" Forest, but does provide about 160,000 AUM's of grazing of which about 75,000 are sheep and 85,000 cattle. Approximately 200 families depend on the Targhee's range for a portion of their livestock range[4]. Range lands are in good condition and water is generally abundant. We get good vegetative response to range improvement projects such as spraying and burning due to fairly heavy amounts of precipitation.

Since the mid 1960's, the Forest has been the site of a massive pine bark beetle infestation. The resulting salvage operations in lodgepole pine stands have and will continue to provide significant amounts of transitory range in areas that have been clearcut.

We experience the usual competition between grazing and other resources. In addition to these, two unique situations are: 1) the need to coordinate grazing and reforestation to protect new timber plantations from grazing livestock and 2) the coordination necessary to grazing sheep in Situation 1 grizzly bear habitat.

The main question is, "How well did we integrate the economics of range management into Forest planning?" Since I expect the Targhee's final

[1]Department of Agriculture, Forest Service, 36 Code of Federal Regulations Part 219, September 17, 1979.

[2]U.S. Forest Service, Forest Service Manual. Chapter 1920 - Land and Resource Management Planning, Interim Directive No. 6, March 10, 1980.

[3]Department of Agriculture, Forest Service, 36 Code of Federal Regulations Part 219, September 30, 1982.

Robert G. Williams is the Forest Planner on the Targhee National Forest, St. Anthony, Idaho.

[4]U.S.D.A. Forest Service, Targhee National Forest, A Briefing Guide for Planning on the Targhee National Forest, 1980.

plan to be released in the next month or so, and since appeals and court suits seem to be the rule rather than the exception these days, I won't answer that question directly. Rather I will explain what we did and let the audience be the judge.

It's my impression that range conservationists cut their teeth doing allotment analysis. Throwing hoops, identifying plants, clipping and weighing grass - they can do it in their sleep. We need little help in making good projections of supply. Existing allotment management plans provide an adequate data base. Although some of our allotment management plans are outdated, they are still adequate for making supply projections. Costs of supplying additional forage are well documented and readily available. An area where additional information would have been helpful is in transitory range. In the Targhee plan, we made some projections but we could have used additional data to answer questions such as: "What happens to the transitory range as trees come back?" "What are the effects on range of thinning?" "Does a short rotation age of 60 years have significant benefits for range as opposed to longer rotation ages?"

Demand analysis is a different story. We simply don't have good data when it comes to estimating demand, particularly when we introduce the requirement of determining price quantity relationships. We are able to make some rough estimates of demand by considering projections for red meat consumption, population projections and other existing and time tested methods. Although we learned a lot about the future demand for red meat, I'm not sure how applicable that is to demand for grazing on the Targhee National Forest.

My first experience working with the Forest Service was doing research at Utah State University under the supervision of Dr. Nielson on the subject of defining market areas for livestock grazing. At that time, we showed fairly conclusively that 1) different market areas do exist for grazing on National Forest lands and 2) that demand, as reflected by the price permittees were willing to pay, differs between market areas[5].

Demand is also influenced by price, availability of substitutes and other factors. Now this is pretty heavy stuff for an economist on a National Forest (assuming that the Forest has an economist), and it would seem to be an area where Research can provide some help.

Specifically, if we are going to be serious about estimating demand for grazing, we need to identify areas where the determinants of demand are similar, look at the cost (price) of both fee and nonfee uses of grazing and then develop some price quantity relationships for each area.

[5]Robert G. Williams, "Determining Market Areas for Livestock Grazing". MS Thesis, Utah State University, Logan, Utah, 1969.

This won't happen, however, if we wait for individual Forests to do the job. They simply don't have the capability; the study needs to be directed to a Regional and National level.

As it turned out on the Targhee, we ended up estimating future demand for grazing by looking at history. For example, when permits change hands, are takers readily available? What price does the permit sell for? Are there vacant allotments? What is the level of nonuse? By using this type of information, we were able to make some fairly rough estimates about the quantity of grazing that would be demanded. We did not, however, develop any price quantity relationships.

I'm happy to say that almost every Forest in the Intermountain Region can do a creditable job of economic efficiency analysis. We have several models with which to do the analysis and the job is relatively straight forward. The results, however, are only as good as the input. I believe we make good predictions as to outputs and costs. The problem, comes from the benefit side. As with demand, we don't have good data on the value of an AUM for individual Forests. The value (price) of forage will vary from area to area, and will be affected by demand and supply. If we have trouble estimating demand and the price quantity relationships, it follows that the value we use to reflect benefits will also be lacking.

The alternative is to use a value set in the RPA, a Regional value or whatever else is available. This, I believe, is unacceptable and points to an area where Research would be beneficial.

It is clear that the direction in Forest planning is to use present net value as the basis upon which to develop and compare alternatives. Obviously, the resources that will come out ahead are those that show positive contributions toward present net value. Just showing positive contributions toward present net value in itself will not be enough. The competition among resources we are seeing today assures that our economic analysis will come under close scrutiny. We will need to be able to use values that are realistic and defensible. Present net value figures are no longer accepted by everyone simply because they are generated by a computer. People are now looking at and questioning the inputs we use in our economic analysis. We need to be able to support them with solid research.

Individual National Forests can adequately take care of the supply and cost side, but if grazing is to get a fair shake, we will need some help on the demand and price side from somewhere.

We are in fairly good shape on the distributional effects assessment. Most Forests have access to and are using an input/output model. We have come a long way in this area during the past few years. Some of our coefficients may be outdated and we often find ourselves extrapolating coefficients from a State or Regional study to a local area. If Range Management was my game, I would look at the coefficients that are now being used in Forest level planning that are affected by the level of grazing.

In conclusion, we have come a long way in our Forest level economic analysis. Obviously we still have a long way to go, particularly if we are going to meet the intent of land management planning regulations. Most National Forests do not have the capability to develop the necessary data. Once we have the information, we will have the tools and ability to perform the necessary analysis. I imagine we will be looking to Research to meet some of these needs.

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ECONOMICS AND MULTIPLE USE MANAGEMENT ON FEDERAL RANGELANDS

E. Bruce Godfrey

ABSTRACT: "Multiple use" has been one of the guiding principles used to manage federal lands for more than twenty years. Unfortunately, the application of this principle is commonly fraught with problems. Some of the most difficult problems that must be solved by economists are outlined and evaluated in this paper.

INTRODUCTION

The principle of multiple use management has a colorful history that essentially dates back to Secretary of Agriculture James Wilson's famous letter to Gifford Pinchot (see Behan 1967 for a review of much of this history). It also represents a concept that has been the subject of writers for about 50 years--references to multiple use management are plentiful and diverse. It is generally hailed by resource managers as their "guiding light" while others view it as a myth (Hall 1963, Sterling 1970). Perhaps only "conservation" is more widely used and more loosely defined. As a result, it is commonly interpreted by interest groups to meet their own needs or desires--anyone who has attended a public meeting conducted by the Forest Service (FS) or Bureau of Land Management (BLM) recognizes how commonly different interest groups interpret multiple use management in different ways. Many of the divergent opinions stem from differences in the area upon which the concept is to be applied--Ciriacy-Wantrup (1938) was the first writer I've found who recognized these differences. The first view or approach suggests that multiple use must be applied to each parcel of land and represents a "resource oriented" approach. The second or area oriented approach (Ridd 1965) suggests that a single use may "dominate" in one area while another use will "dominate" in another area and the two areas represent management from a multiple use perspective. These differences of opinion were made especially clear in the Public Land Law Review Commission (PLLRC) report (1970) and the associated hearings. Perhaps no other recommendation in the PLLRC report received as much "heat" as the recommendation that Forest Service and BLM lands be managed in accordance with "dominant use" principles. As a result, numerous writers (e.g. Pyles 1970) commented on the strengths and weaknesses of "dominant use" management. Some suggested that "dominant use" was not "multiple use", while others indicated that it was the essence of multiple use management. These discussions did not, however, lead to a consensus of opinion and it was inevitable that the disagreement concerning what constituted "multiple use" management would continue to exist.

E. Bruce Godfrey is an Associate Professor of Economics at Utah State University in Logan, Utah.

AGENCY ADMINISTRATION AND MULTIPLE USE

While these differences in philosophy may appear to be purely academic, they have two major implications that must be considered. First, it seems fairly clear to this writer that the BLM and Forest Service have, defacto over time, moved toward the dominant use philosophy as reflected by wilderness area designations and their concern with riparian habitat and mineral development. As a result, major shifts in use have occurred from forestry and livestock to recreation interests (Godfrey, 1978) and other special uses. While some of these shifts can probably be justified, it seems curious to this writer that they have been justified on the basis of an increasing demand for recreation at a low or zero price while the other demands, with increasing fees, have declined relative to recreation. This suggests it is unlikely that the demand for recreation on federally administered lands would have increased as rapidly had the fees charged for recreation increased as much as they have for timber, livestock grazing, or minerals (Godfrey 1982). Surely, the most rudimentary use of economics would have predicted these differences in the quantities demanded. Consequently, the general taxpayer through Forest Service and BLM policies, actions and allocations is subsidizing these user groups in a major way (Godfrey, 1982).

The differences of opinion concerning what constitutes multiple use management also have a direct impact on the economic models used. Furthermore, the theoretical construct used has a great deal to do with the research that is undertaken and what answers/solutions are sought.

ECONOMIC THEORY AND MULTIPLE USE

Essentially every economist who has written on the subject of economic theory and multiple use has used a production function approach (e.g. Brown 1976; Lloyd 1969; O'Connell and Brown 1972; Gregory, 1955; Muklenberg 1964) and has outlined the criteria for the efficient use of a parcel of land by two or more competing uses. Most economists would agree that the product/product or production possibility frontier is the proper approach to use if the efficient use of a particular area is being considered. However, the following problems make this theory difficult if not impossible to apply.

Product Transformation

Most economic discussions of multiple use have either implicitly or explicitly assumed production functions of the following type:

$$y_1 = f_1(x_1, x_2, \ldots, x_n, y_2)$$

$y_2 = f_2(x_1, x_2, \ldots, x_n, y_1)$

where

y_1 = one product such as cattle

y_2 = second product such as deer

x_i = fixed bundle of inputs such as water, grass, browse, cover, etc. needed by the two products.

From this model a product transformation curve is derived such as the one shown below.

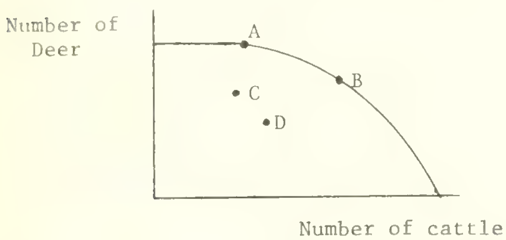

Figure 1.--Hypothetical transformation curve between deer and cattle.

A movement from point A toward point B is said to be efficient if the relative value of cattle is greater than the relative value of deer at point A. But what is assumed if we are on the transformation curve and what is assumed as movements are made along the transformation curve? First, it can be shown that it is necessary to have all inputs allocated efficiently (MRS = Px_1/Px_2) before one can be on the product transformation curve. However, it is doubtful that these conditions hold for most publically (or privately) administered lands. This suggests that most resource allocation decisions are made someplace interior to the product transformation frontier such as a movement from point D to C in figure 1. This also suggests that more effort could (should) be allocated to research that would improve the efficiency of public institutions (McKean 1972) and thus move society toward the production frontier--this is what is implicitly implied by many range managers when they contend that "properly managed" rangelands could produce more livestock and wildlife with no additional resources. As a result, research efforts that are designed to find the most efficient point on the production possibility frontier (MRPT = $Py_1 \div Py_2$) will not be successful if one can not be sure if the movements are in fact movements along a production possibility frontier.

While the above contains many fruitful areas for research, most efforts to estimate a product transformation curve for range products will fail because the above theoretical scenario is incorrect or at least incomplete. For example, a movement from A to B assumes that the fixed bundle of inputs (x_i) remain constant. However, essentially all of the range research I've reviewed refutes this assumption--i.e., the bundle of inputs does not remain constant when more or less of one or more species graze an area. This suggests that the following functional relationships apply.

$y_1 = f_1(x_j)$

$y_2 = f_2(x_i)$

$x_i = f_3(y_1, y_2)$

$x_j = f_4(y_2, y_1)$

where for example,

y_1 = one product such as cattle

y_2 = a second product such as deer

x_i = bundle of inputs consumed or used by cattle

x_j = bundle of inputs consumed or used by deer

and where

$x_i \neq x_j$ which implies that the two outputs (y_1 and y_2) need not use the same bundle of inputs (e.g., sagebrush). This theoretical scenario suggests that effort be expended to estimate the technical externalities (Buchanan and Stubblebine 1962; Bator 1958) associated with using range lands--i.e.

$$\frac{\partial y_1}{\partial x_j} \gtreqless 0 \quad \text{and} \quad \frac{\partial x_j}{\partial y_2} \gtreqless 0 \quad \text{or} \quad \frac{\partial y_2}{\partial x_i} \lesseqgtr 0 \quad \text{and} \quad \frac{\partial x_i}{\partial y_1} \lesseqgtr 0$$

which is not the same as $\frac{\partial y_1}{\partial y_2}$ when x_i and x_j are assumed to be constant under the traditional approach that has been advocated by economists. This does not mean that the traditional approach cannot be used but that care should be used to ensure that the correct theoretical construct is applied. For example, when timber is removed, more forage is generally made available for grazing animals because grass, forb and browse production is enhanced. This suggests that livestock grazing and timber production are competitive. However, the grazing of areas that have been seeded to trees will generally enhance tree growth because competition for space, nutrients and sunlight is reduced which suggests a complementary relationship. However, it must be remembered that these differences exist because the undergrowth (grass, forbs and browse) did not remain constant. This suggests that there is generally not a direct functional relationship between timber growth/production and livestock grazing. However, there is a direct functional relationship between timber growth, forage production, and livestock grazing. Thus, care must be exercised in carefully defining what variables are being measured.

One should note that the traditional biological definition of competition used by range scientists is analogous to the externality approach suggested above because competition is defined to occur when the same input is desired by two or more species (e.g., Salter and Hudson 1980; Stoddart and others 1975, chapter 11; Heady 1975, chapter 9) such that some input (water, forage, space) is limiting--i.e.,

$$\frac{\partial y_2}{\partial y_1} < 0 \quad \text{because} \quad \frac{\partial y_2}{\partial x_i} > 0 \quad \text{and} \quad \frac{\partial x_i}{\partial y_1} < 0.$$

This is also the same conceptual approach used in operations research (e.g., LP and goal programming models) and simulation models--input constraints become binding when forage or habitat requirements are given or defined. This suggests that the traditional product transformation curve suggested by most economists in the past is generally not applicable to multiple use decisions on rangelands, except as a conceptual construct, because a traditional production possibility frontier, with a fixed bundle of inputs, cannot be estimated for livestock grazing and most other uses of rangelands.

Prices

If a production possibility frontier could be estimated, the efficient use of resources will occur when the rate of product transformation is made equal to the ratio of the prices of these products (any economic principles text reviews this theory). Unfortunately, comparable prices for many of the products produced on federal rangelands do not exist. For example, it may be possible to estimate the value of livestock and range forage for domestic livestock but the methods used, to date, to value recreation or hunting do not allow one to derive the value of the deer or the forage they consume. Some misguided efforts have been made to derive these values but a fallacious assumption is needed as the following example illustrates. Suppose a demand curve has been estimated using one of the methods available (see the publication by Dwyer and others 1977; for a review and evaluation of these methods) and an average consumers surplus of \$50 per recreation day is estimated. It is then determined that an average hunter spends five recreation days to "bag" his deer. It is then assumed that the deer is worth \$250 (\$50/day x 5 days). However, this implicitly assumes that the only value that the hunter receives is from "bagging" the animal. However, the \$250 represents the consumer's surplus of the total experience not just the deer that is bagged. This problem is analogous to having a \$20 steak dinner in a nice restaurant and claiming that the value of the steak alone is \$20 and that the other items consumed (atmosphere, waiter services, other food, etc.) are worth nothing. Therefore, it is necessary to separate out the value of the other associated services before the value of the deer can be determined. Furthermore, numerous writers have questioned the validity of the methods used to value recreation (Schuster 1982).

However, even if many of the theoretical objections raised by these authors were overcome, there remain a number of problems that must be solved before they can be used in allocating competing uses. First, the bidding game and travel cost methods yield average consumers surplus values. It is therefore necessary to obtain comparable values for all resources being allocated (e.g., both consumers surplus as outlined by Martin and others 1978). Furthermore, both value estimates must represent marginal values rather than average values if marginal changes in use are being contemplated. For example, the values for most recreational use of federal lands may be large on the average but if consumers are rational and if no fees are charged for using federal lands, the value of an additional or marginal unit may be very small or zero. Thus, allocations that favor recreation may not be justified at the margin. Additional problems are raised where option and existence values (Bishop 1982; Miller, 1981) are considered. While option and existence values probably exist for endangered plants and animals it is doubtful that they apply for species that are plentiful. Furthermore, it is doubtful that these values are large at the margin when increasing rather than decreasing numbers are being advocated. However, even if all of the above problems were overcome, no defensible method has been discovered for making the transition from consumers surplus values per visitor day to the value of a deer or other form of wildlife. Some have suggested however, that the product transformation curve should involve livestock and hunting (rather than livestock and deer) but this raises its own set of problems (e.g., do hunting values change when the number of deer that exist in an area increase or decrease) that are beyond the scope of this paper.

The above discussion has emphasized the need for empirical work concerning the biological relationships associated with using rangelands as well as the need to have comparable prices or values. Unfortunately, these are not the only problems that exist because many range managers (and economists) confuse allocation problems associated with technical (biological) externalities (e.g., impact of livestock on riparian habitat) and those associated with user preferences or utility user satisfaction (such as how recreationists perceive the presence of wildlife, wild horses, or a strip mine).

USER SATISFACTION

Popular literature (e.g., Outdoor Life, Sierra Club Bulletin) is replete with examples that contend that recreation and livestock grazing are competitive. However, I have not been able to find any empirical evidence that both livestock and recreation directly compete for the use of any input (space used for camp sites and water holes is probably the only exception). Therefore, from a biological point of view these two uses would not be competitive (∂ recreation/∂ livestock grazing = 0)--i.e., the amount of recreation does not change when livestock grazing in an area increased--because the removal of forage by livestock (∂ forage/∂ livestock grazing) has no effect on recreation (∂ recreation/∂ forage = 0). They may be competitive if forage is an intermediate product, however. For example, the consumption of forage by livestock (∂ forage/∂ livestock grazing) may affect the amount of forage for deer (∂ deer/∂ forage) which could affect hunting and recreation (∂ recreation/∂ deer). However, it is doubtful that most recreation interests and livestock grazing are directly competitive from a biological point of view. This does not mean however, that these uses are not competitive or complementary as perceived by man. For example, a person may perceive biological diversity, deer, livestock, or other humans as being either a positive or negative influence on a recreational experience. This then represents a fruitful area of research

which lies at the heart of most of the literature concerning recreational carrying capacity (e.g., Godfrey and Peckfelder, 1972; Wagar, 1974; Stankey and Lime, 1973). It also represents an area of research where social scientists can contribute to the resolution of apparent conflicts between user groups as perceived by rangeland administrators but which have little, if any, empirical basis.

ECONOMICS AND AREA ORIENTED MULTIPLE USE MANAGEMENT

The preceeding discussion has emphasized the need for research concerning resources and their interrelationships. Those writers who have advocated a dominant or single use philosophy have generally failed to recognize that these interrelationships must be determined before a dominant use for an area can be determined or justified using traditional economic theory or models. Similarly, however, studies designed to resolve possible multiple use conflicts must make greater effort to recognize the potential for allocating resources in a suboptimal manner if a regional or national perspective is not used. It is recognized that this perspective often leads to a central decision making framework but these broader issues must be considered. For example, many of the ranchers in Wayne County, Utah, will be affected by three BLM grazing EIS's (Mountain Valley, Parker Mountain, and Henry Mountain) and two similar Forest Service evaluations as well as proposed elimination of grazing of Capital Reef National Monument. Each of these planning efforts and associated decision documents involve reductions in the use of federally administered lands. It is not likely that any one of these decisions will have a "significant impact" on these operators but their aggregate impact is probably large. Similarly, administrators must recognize how recreational developments or allocations in one area can affect patterns of use in other areas (Knetsch 1977; Cuddington and others 1981)--i.e., what is the role of substitutes in resource valuation and multiple use allocations.

CONCLUSIONS

Perhaps the PLLRC report best summarized the usefulness of the concept of multiple use when they stated the following.

> . . . the meaning of the term "multiple use" as a general expression of land use policy should be distinguished from the manner in which land use and management actually occur in a particular area. We recognize that nearly all public lands are capable of producing a variety of values, but we do not believe that this means that these lands are necessarily managed for multiple purposes. It is also our belief that multiple use has little practical meaning as a planning concept or principle.

This does not mean however, that economic principles or multiple use concepts cannot be used in helping make these decisions. It does suggest however, that they must be used wth care. Furth[ermore], the above discussion suggests the followin[g]

1. Federal land administrators need to become in[formed] concerning when and how economic infor[mation] can be used in helping resolve user/us[er] conflicts.
2. There is often a large gap between the theore[tical] solution and the correct use of economic methodology. As a result, it is easy for som[e] to misapply the tools available.
3. The factors and relationships that are critic[al] to a decision must be carefully identified before the methodologies outlined previously ca[n] be applied. For example, what factors (biolo[gical] and/or social) make particular uses competitive?
4. Much of the information that is needed for an economic analysis is either not known or misdirected. This suggests that research is needed in the following general areas:
   a. The valuation of wildlife/recreation activ[ities] such that the results can be compare[d] to values for traditional commercial uses including the role of substitutes.
   b. Estimation of the interactions between the use of various resources by wild or domest[ic] animals as well as man and how or when foo[d], habitat, and space requirements overlap.
   c. The impact of other uses on recreational activity and satisfaction.

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EXTERNALITIES CAUSED BY MULTIPLE USE ON PUBLIC RANGELANDS

Fred J. Wagstaff

ABSTRACT: Multiple use on public lands often creates spillover impacts (externalities) on adjoining landowners. Wildlife are a good example since they use lands without regard to ownership. Such use competes for forage with domestic animals and can adversely affect rancher income. Ranchers are seeking recognition of this contribution toward providing wildlife habitat and forage.

INTRODUCTION

This paper stems from discussions with members of the National Cattlemen's Association and Forest Service personnel over the past several months. The livestock industry is expressing concern that private land contributions in providing habitat and forage for wildlife are not adequately recognized by the public or land managing agencies.

Further problems arise in that ranchers often perceive wildlife-oriented multiple use decisions on public rangelands as reducing available public land grazing, and in some cases, also imposing additional competition upon their private rangelands. This type of problem could be particularly significant in the West because of the physical and economic relationships between public and private lands.

Because many western ranches are tied closely to use of public rangelands, the actions of managers of these public lands directly affect the profitability of livestock raising. Decisions to increase wildlife on public lands will affect all lands used by animals during their life cycle regardless of ownership. Many game animals have dietary overlaps with domestic livestock and compete to some degree (Smith and others 1957). The competition may become very severe when critical wildlife habitat is involved (Riordan 1957). Often winter and spring game ranges are more limited than summer and fall ranges. A high degree of competition can result when livestock grazing exists at high levels (Skovlin and others 1968; Julander 1955). As a matter of policy, public agency managers are required to allocate a portion of range forage to wildlife use (Forest Service Manual 1978).

The purpose of this paper is to provide a brief review of the concept of externalities, some examples showing how externalities arising from public rangeland use policies are causing problems, and a suggested course of research to address these problems. The paper was prepared to stimulate thinking and discussion about a perceived problem rather than reporting specific research results.

Fred J. Wagstaff is a Range Economist at the Shrub Sciences Laboratory, Provo, Utah; a unit of the Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

GENERAL ECONOMIC THEORY

It is generally accepted that actions taken by individuals or firms often have consequences that affect others and are beyond control of those affected. When these impacts on others are positive we say an external economy exists. When negative consequences occur to others it is called an external diseconomy. In some literature these effects are called spillovers (Watson and Holman 1977).

The concept of externalities has traditionally bee explained by reference to pollution problems where actions of one party cause a reduction in quality of a resource, such as air or water, for another party. The explanation of why one party may deliberately choose to cause some reduction of quality of another's environment is somewhat complex.

The "law of commons" or concept of public resource provides a partial explanation. In essence this concept suggests that anyone looking after his bes interest will not be fully concerned with the impact of his actions upon the common resource. A worst, he will only be affected by part of a reduction in quality. He is better off absorbing some negative impacts than if he were to bear the cost of treating the pollutant (internalize the cost). In other words, private benefits and costs may well differ from social benefits and costs. A common example is the overuse of public rangelands prior to establishing regulations and setting up administrative agencies to manage them. Any singl livestock operator had no incentive to reduce use because someone else would use what he did not.

This contention is supported by the traditional viewpoint of "the economic man" who is driven by profit maximization (and efficiency in production) To maximize profits a firm wants to produce at the lowest possible cost per unit consistent with maximum net return. Although Martin (1966), among others, has documented the fact that ranchers ofte have goals other than maximum net profit, efficien in the production of saleable livestock remains a major goal for livestock producers. Anything that causes increases in costs is of concern because this is the part of production that is under the most control by the rancher. Individual ranchers have little control over selling prices of livesto due to a highly competitive market structure.

Following the concept of efficiency a bit further, we see that ranchers will attempt to use the least costly feed for livestock production. Anything that reduces the amount of a relatively cheap feed source will increase production costs. The source could be public land forage, or even private range forage if fees, competition with other uses, weather, or other factors increased its cost. If the only change in the production process is to replac the cheap feed with more expensive, but not necessarily better, feed then net profits will be reduc

A rancher may respond to less public range forage by leasing private rangeland.

A Pollution Example

Because pollution problems are classic examples of externalities it would seem beneficial to review an example. Let's think of a water course as the recipient of effluent from some production facility. If viewed from the polluting firm's standpoint, production costs are being minimized because the cost of dumping effluent into the stream is less than treating the effluent. The downstream user views pollution as an added cost if the water must be treated prior to use. Production costs are increased over the prepollution state due to the costs of treatment.

Whether this situation is good or bad from society's point of view depends on whether treating the water downstream is the most efficient way of handling the pollution. As pointed out by Kneese (1964), if the cost of treating the effluent at the source is less than treating the water down stream there would be a net social gain from requiring treatment at the source.

Several writers have suggested various schemes of payment or compensation ranging from discharge taxes to subsidies for treatment facilities (Krutilla and Fisher 1975). Basically the argument of those suggesting such schemes is that society would be better off by paying the party who could most cheaply clean up the pollution. Krutilla and Fisher define costs and benefits as:

PC = Private cost of treatment
PB = Private benefits from treatment or discharge without treatment
SB = Benefits to society from treatment
SC = Costs to society for treatment

They then argue that if $PC < SB$ and $SC > SB$, then society could afford to pay up to the point that $SC = SB$ although $PB > PC$ will also result because all charges in PC may be covered by the payment.

Such an action may well be questionable from an equity point of view because of the transfer payment to the party treating the pollution. It might be that $PC \geq PB$ for a party bearing the tax.

Another method of causing a cessation of pollution has been the class action lawsuit. In an action of this type, courts will allow persons with minor interests to band together to seek legal remedy for damages. If successful in this action, the group would require the polluter to internalize the cost of treatment facilities. Such an action would affect the profit structure of the firm and its competitive position by making production more costly while none of the beneficiaries would directly reap substantial benefits.

Rangeland Examples

There are many examples of externalities involving rangeland use, but only two will be given to illustrate the point. An external economy exists for many areas in the functioning of rangelands as watersheds. The beneficiary of added runoff from range management may be many miles downstream and bear no portion of any costs associated with the production of additional water. In most western States, water rights have been perfected and are recognized as property rights which can not be abridged without payment. This means that the owner of the watershed cannot charge the user of the water, use it himself, or reduce the quantity or quality. Recent court decisions have ruled that even the Federal government cannot use more water than needed for livestock purposes on rangelands without perfecting a water right under State law. The implicatons of such a ruling are great because almost all uses of lands in the West depend on the use of water.

Wildlife present an interesting situation because they are considered to be property of the State and as such a common resource to a degree. Some species of western wildlife range over a fairly large area during a year to meet nutritional requirements (Skovlin and others 1968). During the course of a year it is not uncommon for some animals to use State, Federal, and private rangelands as they migrate, usually as a function of snow depth and vegetative growth stage (Kufeld and others 1973; Robinette and others 1977).

Hunting wildlife, even on private lands, requires purchase of a State license or permit. Game numbers are managed in a gross sense by the State Fish and Game Department through setting seasons, bag limits, and numbers of permits. Little evidence indicates that license fees are a limiting factor for resident hunters. Considerable evidence suggests that license fees do not represent a large portion of the value attached to game animals (Wennergren and others 1973). Considerable consumer surplus is believed to exist for wildlife users, although techniques for estimating it for a given situation have not been completely successful.

Many ranchers in the West do not charge for hunting on private lands either because the game is not on their lands during hunting season or for various personal reasons. However, it is clear to even the casual observer that private lands provide significant wildlife habitat in many areas. Almost all pheasant habitat is on private lands; other species such as antelope are found mainly on Federal lands.

With the exception of damage payments, the States generally do not make payments to landowners who contribute to the forage requirements of game animals. The State of Wyoming did return a portion of the antelope permit value to the rancher for a time in an attempt to open more lands to hunting. Unless the resources used by the wildlife on private lands have no alternative use (zero opportunity costs) there is some loss to the private owner. The degree of loss depends on the value of alternative uses such as livestock production or other activities.

It is well known that dietary overlaps exist between livestock and big game (Kufeld and others 1973; Riordan 1957). The degree of competition varies with season, location, climatic variables, and other circumstances to the point of preventing generalizations.

Range revegetation projects have been completed on hundreds of thousands of acres of public and private lands in the West. One purpose of government-sponsored projects is to improve wildlife habitat with the end purpose being greater recreational opportunities. If this improvement causes an increase in wildlife populations, the intermingled lands required to meet habitat requirements will receive additional use. This increased use of forage by wildlife may increase competition with livestock and adversely impact ranch costs and incomes. This is a case where a public agency decision causes external diseconomics to occur--symbolically $SB \geq SC$, but $PB \leq PC$--social benefits may equal or exceed social costs, but private benefits maybe are less than private costs. This suggests that society or that part of it receiving the wildlife benefits is being subsidized by the rancher or other private landowner. This is a case of induced external diseconomy as viewed by the livestock producers.

DISCUSSION

Is it fair? Should private individuals be forced to subsidize another group? Of course, we must realize this is a two-edged sword. If we were to decide that all contributors to wildlife production should receive full value for their contribution, some landowners who now charge for hunting may have to share their revenues. In the general sense, societal welfare would not be reduced by redistribution of benefits and costs among individuals. If $SB \geq SC$ society would want to increase wildlife populations.

Of course, the rancher who must share limited forage with wildlife and yet cannot directly share in the benefits has little economic incentive to produce more wildlife or in fact even maintain current numbers. His costs are increased with no corresponding increase in benefits. Ranchers do have an economic incentive to change the system so they can share in the benefits, but may not have the political power to make the needed legislative changes. Consumers (hunters and other recreationists) currently enjoying the consumer surplus, would be expected to resist any change that would reduce this surplus through increasing the price of hunting or nonconsumptive recreational uses of wildlife.

RESEARCH NEEDS AND OPPORTUNITIES

Much information about the general nature of externalities of rangeland use exists and the theoretical base for further study appears adequate (Watson and Holman 1977). However, information concerning the magnitude of the problem in real or relative terms is largely lacking. Considerable study is needed before informed judgments can be made about the distributional issues arising from externalities of wildlife rangeland policies.

For example, I know of no method that estimates, on a recurring basis, the amount of forage harvested by game animals from lands of various ownership. In fact, we have real problems in estimating numbers of game animals. It would be also be necessary to acquire information on dietary overlap of various species for different seasons and to translate this into transformation or tradeoff functions for a specific case study. Were this done, the physical parameters of the problem would become comprehensible, if not manageable. Although much work on diets and overlaps has been published, much remains unknown. Several investigators have reported research indicating little conflict on "properly stocked" ranges (Smith 1961; Skovlin and others 1968; Kufeld and others 1973; Smith and Julander 1953; Riordan 1957; Johnson 1962; Robinette and others 1977). These authors, however, indicate there can be severe competition on overstocked ranges with concurrent use.

Once the physical data have been assembled, analyzed, and evaluated, an economic analysis can be applied. Or can it? To solve the problem, the relative value of products resulting from alternative uses of the forage is necessary. This means, that as a minimum we must be able to determine the value of recreation use and livestoc use of the forage. Because much of this information is extra-market in nature, the going will be tough and slow and subject to much disagreement.

The problem, or at least certain aspects of it, seems amenable to research. A start would be to determine the magnitude of the problem. Perhaps the National Cattlemen's Association could help by providing estimates of big game animals spending time on private lands. State Fish and Game Departments could also help.

A second avenue for research would be to determine for specific situations (a case study approach), the actual competition for forage and the resultin economic impact. This study could look at levels of use and season of use. This would address the concept people hold about the deer-livestock transformation function. Intuitively, the hypothesis to be tested is that a combination of uses will yield the greatest net social benefits. A companion hypothesis is that a combination of uses would also maximize net private or rancher benefits. Although not fully transportable, the information gained would help define the problem.

Research could also yield results by looking at the valuation of rangeland goods and services, particularly those of an extra-market type. This information is needed if sound judgments are to be made about management of rangelands, both public and private.

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FIRM LEVEL ECONOMIC ANALYSIS

Darwin B. Nielsen

ABSTRACT: A basic understanding of the ranch firm as the decision-making unit within the range livestock industry is essential for one working in the area of range economics. Problems of aggregation from the ranch firm to the livestock industry still pose serious limitations for many research problems. Ranch budgeting is an important tool that should not be ignored when training students in several speciality fields related to range economics.

This topic seems so fundamental to any discussion of economics that I have a difficult time in deciding what to say to a group of professional agricultural economists dealing with range economics problems. Yet we probably need reminding of some of the basic premises upon which we base much of our research and policy recommendations. The scope of a symposium on range economics obviously includes both macro- and microeconomic considerations. A review of the program indicates that both areas of economics are being discussed.

My task is to say something about firm level economic analysis within the overall context of range economics. Obviously, the ranch unit is the business firm level economic entity to be discussed. A ranch is a particular business firm which combines resources in the production of agricultural products. This business may be a single enterprise unit or it may combine several enterprises to form the business. Since the ranch is the decision-making unit in the production of agricultural commodities, it is both a buyer and seller. The rancher purchases inputs and transforms them into products which are sold. It should be noted that the amount of products, which will be produced in the aggregate, is determined by conditions confronted by individual ranch producers. All adjustment decisions in resource use must ultimately be made at the ranch unit level. This is important to remember when dealing with public land policy decisions. Although changes in resource availability may be made by the management agency, the ultimate adjustments must be made by the ranch decision maker.

What information can one expect to gain by a study of the ranch firm? First, a study of the firm could provide one with an understanding of the ranch business as it now exists, which would include sources and levels of income, costs of doing business (fixed and variable), the capital investment required, and the combination of resources required to make the ranch a functional business unit. Second, courses of action may be found that would lead the producer to make more profitable use of his resources. The third reason for studying the ranch firm is to be able to predict the consequences of changes in economic conditions on the production of the ranch and, in turn, on the aggregate amount of products which will be available for consumption. A related reason for studying the ranch firm is to estimate the economic impact of proposed changes in public land use. The environmental impact studies of the BLM have initiated a great deal of interest in studies of the ranch business.

From a societal point of view we are interested in seeing if ranches have the capability of producing more product from a given level of inputs; if this can be accomplished society gains in that a great quantity of goods is available for distribution among the people.

Early in the development of range economics as a study area, it was recognized that aggregation to a population from a sample was a problem. It seem that within the general area of range economics we have several problems of defining which firms are part of the system we are concerned about. Do we limit ourselves to a study of ranches that get a "substantial" amount of their forage from rangelands? If we do this, we are left with a decision as to how much is "substantial." We also have another problem in that we have only considered a small portion of the firms that produce sheep and/or cattle. When one analyzes the expected impact of changes within the range livestock industry on the total livestock industry, he needs to know about the economic structure of the entire industry. On the other hand, when a change from outside is expected to impact the range livestock industry, we need to know the structure of this segment of the industry.

The livestock industry is characterized by a wide variation in the size of the units that produce cattle and sheep. The size of these units vary from a few head of livestock on a farm to ranches with several thousand head of livestock. If one analyzes the size distribution of producers, he would find the majority of the producers fall in the small size end of the spectrum; and the majority of the livestock are produced by a few large operations.

Public land agencies are faced with the same problem of wide variation in size of grazing permits. In some cases the land managers would like to ignore the problems of the small permittees, less than 2 head; however, they often carry considerable political influence that cannot be ignored.

Size is not the only variable that should be considered when aggregation from firm level data to some other defined population. Baker (1964) discussed spatial classification of ranch firms to increase homogeneity. He also suggested other factors

Darwin B. Nielsen is Professor of Economics at Utah State University, Logan, Utah.

that should not be ignored. "For example, many firms may have much in common by reason of similarities of age, education, or financial condition of the operator; degrees of specialization or mechanization of enterprises; and similarities in the availability of off-ranch employment of labor and other resources used in the production process."

USDA has used a combination of spatial characteristics and type of operation to increase the homogeneity of ranch populations from which representative budgets of ranch firms are constructed. For example, some of the budget titles are: cow/calf/yearling enterprise, 50 cow herd mountain area; cow/calf beef cow herd, 1,000 and over head of cows, High Plains subregion; sheep enterprise: over 2,500 head of stock sheep, Mountain subregion, range lambing/public range and sheep enterprise: over 1,000 head of stock sheep, Great Basin subregion, shed lamb/public range.

The difficulties with an extremely heterogeneous livestock ranching industry were discussed by Wheeler in 1962. He found that for a sample of about 500 ranch observations covering a fairly large area, and with parts of the total sample covering smaller subregions within which the ranching operations were thought to be fairly homogeneous, there was a failure of input/output coefficients to cluster in a manner that would justify designation of a representative ranch. Based upon his samples and statistical tests, he concluded that any given ranch operation would be as representative, or as nonrepresentative, as the overall average.

Kearl (1965) concluded the following in a discussion of a paper by Caton on the problems of aggregation. "In view of the extreme heterogeneity of the range livestock industry, the diversity of production conditions, the difficulty of obtaining data which can be said to be truly representative, and the very tentative and unproven state of the arts of making aggregate estimates of production adjustments, it may be worthwhile to allow other people to experiment with the state of the arts for making these estimates. People in range (economics) research might find their time used profitably if they concentrate for a few years merely on attempting to find out what the range livestock industry really is and what some of the important coefficients are.

I am not sure how much progress we have made over the last twenty years in solving the problems of aggregation in the range livestock industry. If we have made significant progress, I am not aware of it. We use the concepts of representative or typical ranches for many of our analyses, but I have never seen a discussion on the methods of moving from the typical ranch to the ranch population if one was trying to estimate the supply response of some change in ranch input.

Budgeting is an important technique that should be given more emphasis in our student training programs. I looked through some of the new textbooks on farm management. None of them treated budgeting in enough detail that one could go out and construct a farm or ranch budget if all the training he received was that covered in these textbooks. In my opinion an agricultural economist needs to have the experience of going through all the minute details of developing farm and ranch budgets from raw data gathered from ranchers. One of the major accomplishments of the regional research project W-79 was that the assumptions used in constructing ranch budgets were standardized so that comparisons of ranch budgets in different states could be compared. The USDA budgets compiled from the budget generator are good and make the data available to many more of us to use. However, the availability of these budgets does not lessen the need to know how to develop a budget from raw data or to know how to get budget data from ranchers.

We need to know more about how ranchers react to changes in input or resource availability. An analysis of the ranch firm could provide one with insights as to how ranchers adjust to such changes. One might be able to determine which resource substitutions are made and why that particular pattern of adjustments was followed. The problems of adjusting to changes in resource availability are compounded when many ranchers in a local area are faced with the same problems. They are all trying to find substitutes for the same resource and could very well exhaust the supply of substitutes and/or cause their prices to be bid up substantially. An example of such a resource adjustment problem would be one caused by a reduction in public grazing that affected many ranchers in a local area.

Many public range resource managers seem to be reluctant to want to study or learn anything about the ranch firm as part of their information base. The argument goes like this: we are range resource managers not ranchers or livestock managers, thus, we are not interested in the ranch business. This reasoning appears to have some faults. Knowing something about the ranch firm may not directly influence one's ability to manage the public rangeland, however, an understanding about the ranch firm's resource organization which shows how all land ownerships fit together to make a year-round operation may be beneficial to the resource manager. It also may benefit him to see why ranch firms are so concerned about resource management decisions that could impact their weaning weights and calf or lamb crop percentages. Marginal changes in these variables directly impact the rancher's income for family living expenses since the costs of the ranch operation must be paid first. The main point to be made is that the public rangelands can be managed in alternative ways that leave the land essentially the same but may have significantly different impacts on the ranch firm and ultimately on society's demand for food and fiber from these uses of the land. One point made earlier in this paper should be restated: all adjustment decisions in resource use must ultimately be made at the ranch firm level.

A related philosophy of public land management goes something like this: "I am a land manager not a rancher, lumberman, recreationist, wildlife manager or miner. Therefore, I am only interested in maintaining the land base in proper (nondeteriorating) condition for present and future generations." What's wrong with this philosophy of public land management? Public land policy statements usually have some reference to beneficial uses to be made of the land. In my opinion resource managers cannot divorce themselves from the uses made on the land. For example, two different resource use mixes could leave the land in the same biological

or physical condition, but one mix of uses could have economic and/or social benefits much higher than the other mix.

In summary, a basic understanding of the ranch firm as the decision-making unit within the range livestock industry is essential for one working in the area of range economics. Problems of aggregation from the ranch firm to the livestock industry still pose serious limitations for many research problems. Ranch budgeting is an important tool that should not be ignored when training students in several speciality fields related to range economics.

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THE USE OF LINEAR PROGRAMMING

TO ESTIMATE RANGE FORAGE VALUES

C. Kerry Gee

ABSTRACT: The value of range forage for livestock production can be estimated with linear programming models. The usefulness of the resulting estimates is dependent upon the accuracy of data used in the analysis and upon the willingness of users of the estimates to accept assumptions implicit in this technique. This paper outlines limitations and benefits of using LP to estimate forage values.

INTRODUCTION

In October 1979 the Economic Research Service (ERS) of USDA entered into an interagency agreement with the Forest Service (USFS) to estimate forage values for livestock grazing Forest System rangelands including both National Forests (NF) and National Grasslands. Resulting values were to be used in forest planning. Since its inception, the project has generated values for 85 National Forests and National Grasslands. Estimated forage values have ranged from $.05 to $23.35 per animal month (AM). Values for 76 percent of the areas have fallen between $7.00 and $16.00 per AM.

The USFS-ERS contract specified that linear programming (LP) provide the analytical basis for estimation. Details of the methodology are published as a Colorado State University Experiment Station report.[1] General procedures are as follows:

1. Permittees are stratified by kind, type, and size of livestock enterprise.

2. Average enterprise cost and return budgets are prepared for each strata.

3. An LP matrix for each enterprise budget is constructed which will reproduce the budget exactly. Animal Months (AM) of USFS grazing appear as a single row in the matrix.

4. Marginal Value Products (MVP) for forest AM's in each enterprise budget are weighted by total Forest AM's for each strata to estimate a single forest forage value.

The correctness of forage values estimated through this procedure is dependent on the validity of assumptions associated with the LP, correct specification of the LP matrix, and accuracy of the enterprise budget data.

LP ASSUMPTIONS

The LP objective function in this project is defined as follows:

$$NR = \Sigma p_i q_i$$

where

NR = Gross sales minus all costs except interest on land and the forest grazing fee.

p_i = product prices and input costs.

q_i = quantities of products sold or inputs purchased.

The value of NR in the matrix solution can also be produced as follows:

$$NR = \Sigma S_i L_i$$

where

S_i = MVP's of each restricting resource in the LP solution.

L_i = Quantity of each restricting resource in the solution.

The second equation quantifies the contribution of each scarce resource to NR. The MVP for forest grazing measures the dollars added to NR by one AM (given the present size of herd, production, cost structure, and level of technology) or the forage value to the business which is the value needed in forest planning.

LP carries with it some assumptions that can affect forage value estimates:

1. Additivity and linearity--this precludes interaction between production processes and precludes economies of size or scale.

C. Kerry Gee is Agricultural Economist at the Economic Research Service, U.S. Department of Agriculture, stationed at Colorado State University, Fort Collins, Colo.

[1] C. Kerry Gee. Estimating Economic Impacts of Adjustments in Grazing on Federal Lands and Estimating Federal Rangeland Forage Values: Colorado State University Experiment Station Tech. Bul. 143; November 1981. 11 pp.

2. Divisibility--which allows for fractional units of inputs and products.

3. Single valued expectations--all coefficients are known constants.

The first two assumptions should not be concerns in this project since the matrices are constructed to reproduce the current costs and returns for livestock businesses. No adjustments from current size of business or enterprise combinations occur in estimating forage values. The assumption of single valued expectations relates to the accuracy of matrix elements compared with actual performance of livestock businesses using forest rangeland. This does affect the MVP. If initial enterprise budgets are not representative averages of livestock businesses using a particular NF, the MVP will be incorrect.

SPECIFICATION ERROR

Construction of LP matrices in terms of number and kind of equations can affect forage value estimates. Interrelationships between scarce resources and production alternatives in livestock businesses that use forest grazing must be correctly specified. Annual feed sources must be incorporated to describe seasons of use and feed substitution alternatives used by producers. For example, the MVP may be much different for a resource if it is an only feed source in a given month than if it is available over several months and there are other feeds available during the same time period.

ACCURACY OF MATRIX ELEMENTS

As indicated above, accuracy of data is essential to reliable forage value estimates. It seldom occurs that all matrix elements in an LP analysis are known constants. In most cases they are best estimates, without even the benefit of confidence limits. Adequacy of data often is checked either by comparison with information (collected using similar procedures) from other studies or by the accumulated knowledge of the researcher. Accuracy of data is probably the principle concern in estimating forage values using linear programming.

ADVANTAGES OF LP IN FORAGE VALUE ESTIMATION

MVP's generated in LP analyses are sensitive to changes in matrix coefficients. Differences among forests in terms of feed costs, calving percentages, market weights of cattle and calves, livestock prices, etc., are all reflected by variations in estimated forage values. As indicated earlier, values generated in the USFS-ERS project thus far, have ranged from $.05 to $23.35 per AM. Reasons for differences among forests are explainable by reference to the enterprise budgets for the forests. For example, the extremely small value (on the Angelina National Forest of Texas) is low productivity--a calving rate of 70 percent, market weights on steer and heifer calves of 350 and 300 pounds respectively, and 700 pound cull cow weights resulting in gross sales per cow of $149. Sales on most forests in the southeast reach about $250 per cow. The high value (on the Chattahoochee National Forest) was due to a significant proportion of AM's going for dairy stock which affected both sales and costs.

Forage value differences frequently occur between forests in the same geographical area. Values for the Gallatin and Deerlodge National Forests, both in southwestern Montana were $8.66 and $16.95 respectively. A review of the enterprise budgets showed costs per cow about the same on both forests. However, total sales per cow were $274 on the Gallatin and $339 on the Deerlodge. High sales on the latter forest were caused by a higher proportion calves sold as yearlings, heavier market weights for animals sold, and a higher weaning percentage. Differences in LP generated forage values among forests can be explained. Factors found to cause differences among forests in the USFS-ERS project include:

1. Herd size distribution--values for large herds tend to be higher than for small herds.

2. Kind of livestock--sheep usually generate higher forage values than cattle.

3. Type of enterprise--yearlings usually have lower values than either cow-calf or cow-yearling enterprises and cow-yearling enterprises may have higher values than cow-calf enterprises.

4. Sales--high sales per cow may give higher forage values (costs must be checked also). Sales depend on type of enterprise, market weights, calving percentage, death loss, replacement rates, livestock prices, etc., any of which may be the explanatory factor for a difference between two forests.

5. Costs--high costs may cause low forage values (sales must be checked also). Cost differences may be due to amount of supplementary feeds fed, whether feed is produced or purchased, dependence on federal grazing land, labor requirements, etc.

6. Dependency on federal grazing land and season of use may affect forage values.

An important advantage of LP is that differences in livestock production among forests can

be incorporated into the analysis and reasons for differences in forage values among National Forests are identifiable.

SUMMARY

LP will produce forage values which represent the economic contribution of forest grazing to livestock businesses. It will produce values which show differences among forests in the value of this feed source to livestock producers. The correctness of estimated values depends on correct specification of the model and accuracy of the matrix coefficients.

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VALUING RANGE FORAGE ON PUBLIC RANGELANDS

E. T. Bartlett

ABSTRACT: Range forage is an intermediate good that is used to produce other outputs such as red meat, wildlife and associated recreational benefits, and wild horses and burros. Also, society places value on the continuity of range ecosystems and the plant species within those ecosystems. Value of forage grazed by livestock has been determined through: 1) comparisons with market-priced forages and feed sources; 2) capitalization of permit values; and 3) production analyses. Currently, production analyses offer the most promise in deriving demand for public range forage. Studies have been reported that determine value of wildlife and wildlife recreation; however, these values have not been related back to the habitat. Value of forage for wild horses and burros has not been studied by economists but valuation has been reflected in legislation. Agencies are mandated to provide for ecosystem continuity and diversity, but the value of these benefits has largely been ignored by researchers, managers and the budgetary process.

INTRODUCTION

Range includes both forested and non-forested lands which support an understory or periodic cover of herbaceous or shrubby vegetation amenable to grazing or browsing use (Range Term Glossary Committee 1974). Range, like other wildlands, provides many outputs such as recreation, water, forest products, wildlife, and related goods and services but has traditionally been associated with providing forage for livestock. The purpose of this paper is to examine the methods that have been used to determine value of benefits relating to range forage and to the ecological aspects of range resources, and to examine data needs for each method.

Most of the literature on range valuation has concentrated on the value of forage for grazing by domestic livestock and has been associated with grazing fee determination on public lands. One of the earliest studies was conducted in 1916 to determine the value of grazing on private range that was comparable to public lands (Dutton 1953). Numerous studies and recommendations have been made over the years. Godfrey (1981) recently reviewed research needs for forage valuation on range and cropland.

Goods and amenities will be defined in the following section with the concentration on those that use range forage. The approaches that have been used to estimate value of range outputs will be reviewed and examined with respect to usefulness in benefit-cost analysis and valuation of other resource uses or amenities. The final section discusses the data requirements of the different methods.

RANGE BENEFITS

When most people think of range, they imagine cattle grazing on a mountain meadow or a vast prairie. Indeed, range forage for the grazing of domestic animals has been and is an important use of range; however, other herbivores also use range forage. Range forage is an intermediate good that is used to produce other outputs such as red meat, wildlife and associated recreational benefits, and wild horses and burros. Finally, it appears that society places value on the continuity of the range ecosystems and the plant species within those ecosystems.

The amount and quality of range forage varies between ranges and temporally on the same range. In addition, the amount of forage available for grazing depends on the type of animal using that forage. The most common of domestic animals that are grazed on range are cattle. The next most numerous are sheep, although numbers of sheep have declined since the mid-1940's. Some domestic horses are grazed on most range, and goats are present on some ranges in the southwest. The amount of range forage used is dependent on the characteristics of the range, the stocking rate and the types of animals grazed.

Numerous species of wildlife occur on range and derive all or part of their habitat and nutritional requirements from native range. Some of the wildlife species compete for the range resource with domestic animals while other wildlife species might be thought of as complementary users of the range forage resource depending on the range ecosystem and season of use. Most wildlife production studies on range have concentrated on big game species such as deer and elk. Research is needed to determine the joint production relationships between different animal species when present during the same seasons or during different seasons. In fact, little work has been done to determine joint production relationships of different domestic animal species.

In addition to wildlife such as deer and elk, wild horses and burros are present on many western ranges. These animals compete for forage with both livestock and wildlife. While most people have not seen a wild horse or a wild burro, there is a benefit derived from them by society. This will be discussed further in a following section.

Non-use benefits of range include the continuity of the various range ecosystems and the continuing existence of species that are rare, threatened or endangered. Various legislation provides evidence that society places value on continuity of eco-

systems and species. And, in fact, the Public Rangeland Improvement Act of 1977 authorizes funds to improve rangelands without regard to use.

VALUATION OF RANGE FORAGE

The primary focus of the discussion that follows will be on the valuation of range benefits derived from grazing livestock. The valuation of the other benefits has not been prominent in the literature, and the valuations that have been made have been based on the income compensation function approach or the expenditure function approach (Randal 1981).

Domestic Livestock Grazing

Range forage is not a consumer good but an intermediate or producer good that is used in the production of products that are desired by man. It has been classified in resource economics as a market good, as opposed to a non-market good. This is a valid classification in the case of private range that is allocated to users by a market system. However, on lands administered by the USDA Forest Service (FS) and Bureau of Land Management (BLM), grazing has been allocated to those who met federal requirements to obtain grazing permits. Thus, public range was originally allocated on rules for obtaining a permit; however, permits are exchanged in the market system and reflect value above grazing fees.

The value of range forage grazed by livestock is derived from the value of the livestock produced. Thus, the value of range forage is dependent on the values of products produced from range forage, the value of other types of feeds and forage that might be used to produce the products, and the efficiency of the firm. The value of the range forage is the total amount that the firm would be willing to pay for the last increment of forage, or the value of the marginal product.

Several empirical approaches have been used in an attempt to identify the value of marginal product for range forage. The methods can be generally classified as: 1) comparisons with market-priced forages and feed sources; 2) capitalization of permit values; and 3) production analysis.

Comparisons with market-price forages and feed sources.--This approach is based on determining the value of substitutes for range forage in the production process, and adjusting the value for differences in the cost of using different forage or feed sources. The most closely related alternative forage resource has been comparable private leased range. Numerous studies have been conducted since 1916 with the 1966 Western Livestock Grazing Survey[1] and 1977 Study of Fees for Grazing Livestock on Federal Lands (Bergland and Andrus 1977) being the most recent.[2]

[1]The author has not been able to locate a copy of the 1966 study, but it is summarized in Bergland and Andrus (1977).

The premise that is used to justify estimating public grazing value from private grazing values is that firms will bid for both sources to the margin in which case the price of private grazing will equal the price of public grazing (Nielsen 1972). However, it has been shown that the rancher does not pay the full value for public grazing, and that he is not allowed to purchase federal grazing to the margin (Roberts 1963). The approach that has been used to derive an estimate of the value of federal range forage has been as follows:

$$F = MVP - E \qquad (1)$$

where F is the full market value of federal forage, MVP is the market value of the forage determined from private lease rates and E is the non-fee costs of using public ranges such as herding, improvement maintenance and transportation (Nielsen 1972). E adjusts the value to the net differences in using the public forage as opposed to the private forage.

The adjusted private lease rate was the basis for grazing fees from 1969 to 1978, and was recommended as the preferred method in 1977 by the Departments of Agriculture and Interior (Bergland and Andrus 1977). The 1977 study assumed that non-fee costs had increased at a constant rate since the 1966 survey. This assumes that the intensity of management has remained constant over this time period. In fact, many grazing systems were implemented on federal allotments since 1966 which intensified management and increased non-fee costs (Bartlett and Ralphs 1978).[3] This is not a weakness of the empirical approach, but a weakness in the application of the approach.

The private lease rate approach results in the value of range forage at the current level of use. If the value is used in cases where there are only marginal changes in the forage provided, the private lease rate approach can be used if the private range is comparable to the public forage resource (Dyer 1981). The need to use private range that is comparable to the public range is to include consideration of the quality of the range (forage quantity and quality, distributional factors such as water and topography) so that the animal productivity of the two range resources is comparable.

[2]Land appraisers from the U.S. Forest Service and Bureau of Land Management are currently conducting a study on private land lease rates. This is to be completed in 1983.

[3]Bartlett, E. T. and M. R. Ralphs. Estimation of grazing values for the 1980 RPA program. Report of the RPA evaluation work group. Unpublished mimeo, USDA, Forest Service; 1978. 29 p.

It is possible that the private lease rate approach could be expanded to estimate demand for public range forage. The derived demand would then be adjusted to reflect demand for public range forage. There has been no study that has attempted such an approach (Godfrey 1981), although Johnson and Hardin (1955) discussed the factors that effect the demand for pasture forage.

Other forage sources such as pasture, hay or supplemental feeds have been suggested as points of measurement in efforts to estimate range forage value. The use of pasture lease rates would be very similar to the private lease rate described above; however, the problems involved in relating pasture values to range values would be greater. Pastures are generally much higher in productivity than range, and are intensively managed in small units.

The value of hay has been used to estimate value of range forage (USDA Forest Service 1980, p. C-6). A formula was used that multiplied the average animal weight times the average price per ton of hay times a quality factor of pasture. Hay is exchanged in a competitive market and as such reflects the changes in livestock values and other feed source values (Godfrey 1981). Empirical evidence could not be found that relates hay to range forage.[4] A general caution concerning methods that are based on alternative feed sources is that the market price of a substitute is not a good proxy for range forage value, but substitute feeds do influence the demand for range forage.

Capitalization of permit values.--Historically the fee for grazing public range forage has been below the value of the range forage.[5] Because the marginal value of the public forage exceeded the marginal costs of using it, the permits have accrued value. The permit value is the capitalized difference between the marginal revenues and marginal costs. Roberts and Topham (1965) give the value of public range as:

$$V = F + PC \tag{2}$$

where V is the annual value of public forage to ranchers, F is the grazing fee, P is the market value of the grazing permit, and C is the capitalization rate.

[4]The author could not obtain a copy of the original study on which this formula was based. One can only assume that it was derived by some statistical method.

[5]For a discussion of the history of grazing fees on public range, see Dutton (1953), Foss (1959) and Bergland and Andrus (1977).

Several studies have tested the permit value equation (Gardner 1962; Roberts and Topham 1965; and Martin and Jefferies 1966). Gardner (1962) used an expectation model to estimate the difference between private and public grazing charges The difference was capitalized to represent the expected value of the permit. Actual permit values were well below the expected permit values. Gardner argued that this was due to the restrictive rules for qualifying for a permit, and the history of reducing permitted grazing when allotments were reassigned. Roberts and Topham (1965) stated that the fee plus the discounted value of the permit was a good estimte of the value of public forage at the site.

Martin and Jefferies (1966) used regression analysis to estimte the price of ranches as a function of acres of private land, animal units of FS permits, animal units of BLM permits, animal units of state permits, number of breeding animals, steers and heifers sold with the ranch and the year the ranch was sold. Marginal value was estimated for FS and BLM permits. Estimated values exceeded values that would be expected based solely on cattle production.

Martin and Jefferies (1966) hypothesize that there are other returns besides beef production to the permit investment. These include anticipated appreciation in permit value, reduced taxes through tax shelters, ranch fundamentalism and conspicuous consumption. Ranch fundamentalism refers to those that place some value on being in the livestock business and on that way of life while conspicuous consumption refers to those that buy ranches because one who lives in the west should have a "ranch". The argument is that permit values represent benefits in addition to those gained from grazing range forage for livestock production.

If the above argument is true, why were Gardner's expected permit values so much higher than actual values? Martin and Jefferies (1966) state, "The outputs of private rental lands are just as complicated as the outputs on public leases. One should not use private rental land as a standard for comparison, with the implication that private rentals are used for beef production only." Private lease rates may also be influenced by the season in which they are grazed. It is logical that a rancher would lease additional private range only at times when his deeded and public range were limiting. Thus, the values of private leased range may be higher because of the critical nature of the forage in a particular season. In Colorado, for example, changing the amount of spring grazing on public ranges had a much greater impact on livestock sales than changing the amount of grazing in other seasons (Cook and others 1980).

Another explanation of why expected permit values exceed actual values is that the permit value is reduced by the tenure uncertainty associated with permits (Milliman 1962). A recent study in New Mexico shows that while FS and BLM permits have increased in value from 1965 to 1979, the private grazing price index increased at a greater rate (Fowler and Gray 1980). In fact, neither BLM nor FS permits increased in value at a rate equal to the U.S. consumer price index, and BLM permit

value has not increased since 1975 when the grazing Environmental Impact Statement process was started. Thus, uncertainty of permit tenure does influence permit values. In Oregon, Winter and Whittaker (1981) did not find that public grazing rights were statistically related to private-land sale prices during 1970 to 1978. They explained the lack of permit value as being brought about by increasing grazing fees and uncertain tenure of permits.

Another factor that could influence the permit value is option value. Option value is the value in addition to the value of the resource that arises from retaining an option to use the good or service for which future demand is uncertain (Krutilla and Fisher 1975). Ranchers may stock their own range resources conservatively in normal years, and rely on the public range forage at permitted amounts or less than permitted amounts. In periods of forage shortage, they could rely on both resources to survive such periods. Studies using this approach have not been reported in the literature.

To summarize, it has been shown that public range grazing fees have been below the range forage value and that value has accrued to the permit. However, it is questionable that the short-term marginal value productivity of range forage for grazing is equal to the permit value. Permits are issued for ten years so there is a long term value possibly related to an option value. In addition, permits may increase or decrease in value independent of the forage value. In any event, an estimate of range forage value based on permit value results in an estimate of value for the current level of forage provided. To derive demand, estimates at different levels of forage would be needed. However, it is doubtful that such a derived demand would be very useful as changes in permitted use affect the value of the permit due to uncertainties in tenure that are implied. The examination of permit value does give rise to many questions concerning range values.

Production analysis.--Production analysis is an approach (or group of approaches) in which an input is valued on the basis of the production process and resulting value of the output(s). There are basically two ways to approach the problem: 1) empirically estimate the production function, or 2) use operations research to model the relationships based on budget data.

Roberts (1963) suggested that a third-degree polynomial would be appropriate for a public forage production function based on grazing intensity.

$$R = bX + cX^2 - dX^3 \qquad (3)$$

where R is the total physical output times the market price of the livestock realized off the range, and X is the number of cows grazed per section (representing grazing intensity). From this, Roberts derived the MVP of grazing intensity. Most ranges are not stocked considering such a relationship, but are generally stocked at a moderate intensity level.

In the budgeting technique, the total gross value of the firm's output is calculated, and the costs of all variable inputs except range forage are then deducted. The remaining portion of gross value is known as the residual. It is the return to, or value of, the unpriced input (Sinden and Worrell 1979). If the residual is calculated for several amounts of the unpriced input, a demand schedule can be estimated.

The results obtained by budgeting are based on an implicit production function that is contained within the budget and estimate short-run value. Martin and Snider (1980) derived short-run values of range forage in the Salt-Verde Basin of Arizona using a budgeting approach. They also estimated the average and marginal long-run values of range forage by deducting fixed costs from the residual and capitalizing the remainder. This budget study is unique in that forage value was estimated; most budget studies merely report the economic characteristics of range firms.

Linear programming is a technique that has been used to analyze budget data. The residual of the marginal unit of input is known as the shadow price in linear programming jargon. Parametric analysis in which the amount of range forage is varied can be used to calculate the residuals which represent the demand for the unpriced input. This technique has been used to derive demand for FS forage in Colorado (Bartlett and others 1981). The demand was estimated for various livestock prices and under two management schemes: variable herd size and constant herd size. The constant herd size resulted in a demand based on the costs of alternate feed sources while the variable herd size scheme allowed adjustment of inputs and products.

The Economic Research Service is currently using budgeting and linear programming to estimate the marginal value of public range forage in the western U.S.[6] There have also been a number of studies that have assessed the impacts of potential changes in public forage supply and cost on net ranch income, livestock sales and local and regional economies (Peryam and Olson 1975; Olson and Jackson 1975; Lewis and Taylor 1977; Torell and others 1979; Torell and others 1980; and Cook and others 1980).

While linear programming provided a technique to rapidly analyze budget information and derive demand for range forage, results are based on the budget data and the assumptions incorporated with the linear programming model. Budgetary information is rapidly outdated because of changes in operation caused by changing market prices for outputs and technology (McConnen 1976). Values obtained with the uses of linear programming analysis are determined by changes in other inputs, and other resources are valued and reflected in the measurement of any given factor or resource (McCorkle 1956). In fact, it is difficult to

[6]This study is led by Dr. K. Gee and has been supported by the USDA Forest Service and Bureau of Land Management, USDI.

compare the results of various studies unless the linear programming models have been formulated in a similar manner. A set of common assumptions and model formulation rules are needed so that valuation studies are consistent.

Godfrey (1981) mentions five weaknesses that cause linear programming to be biased and not comparable to estimates derived for other benefits. Three of these weaknesses relate to how ranch budgets are modeled, and can be resolved. Another of Godfrey's assumptions is related to the theoretical validity of deriving demand from a fixed proportion production function, which he admits is not a major problem. However, a completely fixed proportion model would result in a linear production function and horizontal demand. This is an area in which recommendations are needed to guide future use of linear programming. Finally, Godfrey (1981, p. 42) states, ".... and perhaps most importantly, the demand function derived from an LP model is generally very sensitive to changes in the price of the output(s) and/or other inputs." This is not necessarily a weakness of using linear programming, but shows that the estimates of forage demand are, in fact, sensitive to the demand shifters.

Other valuation approaches.--Other studies have been made to determine the value of public grazing. Most of these have been done to estimate grazing fees for state-owned range forage and are based on livestock prices and various other factors including carrying capacity (Huss 1955; Harris and Hoffman 1963; Campbell and Wood 1951; and McDowell and Johnson 1964). Most of the results were based on what was acceptable to the leasor and leasee and were not based on empirical estimates of the value of range forage.

Approaches that are used to estimate non-market benefits such as recreation have not been applied to range forage. However, there is a study at Colorado State University that will use a bidding game approach to estimate public range forage value. The resulting values will be compared to those estimated with a linear programming approach (Bartlett and others 1981).

Value of Wildlife Use

Wildlife compete for the same resource base that is used by domestic livestock. Wildlife uses are classified as consumptive, non-consumptive, and indirect or vicarious users of wildlife (Shaw 1982). These uses have been valued by the income compensation function approach or the expenditure function approach as described by Randall (1982). However, these values have not been related back to the habitat that the animals need in order to produce the various wildlife benefits.

Wildlife management programs do influence the amount of wildlife and domestic animals that will be present although there is disagreement on how the resource can be allocated to different animal species. However, range forage for domestic grazing is valued on the site and at the margin. Therefore, recreational values of wildlife should be traced back to a comparable basis in order to provide information concerning the efficiency criterion to decision makers. Admittedly, this is not an easy task, especially since little has been reported on the joint production functions of different species of animals using the same resource base.

Wild Horses and Burros

While wild horses and burros have long been a common feature of many western ranges, their value was largely ignored until the passage of the Wild Free-Roaming Horse and Burros Act of 1971. The bill essentially dictates that the horses and burros will not be disturbed by man; society valued their existence even though most members would never actually observe the animals. The original bill implies a high value since few herd control measures were allowed (Cook 1975). Provisions in the Federal Land Policy and Management Act of 1976 and the Public Rangelands Improvement Act of 1977 modified the control measures allowed and indicate that society values wild horses and burros less than originally thought.

Godfrey (1979) reviewed the wild horse and burro question and found that very little is known of the value. Godfrey has determined the expenditures being made to reduce herd numbers which does not estimate the demand for the animals but might reflect some minimum value that society places on ecosystems being grazed by wild horses and burros. Johnson and Yost (1979) reviewed economic literature that related to wild horses and burros, and reported very few studies or articles on the subject. Suffice it to say that research is needed to determine the existence value of these animals.[7]

Ecological Continuity

Krutilla and Fisher (1975) define existence values as value that individuals have for an environment regardless of the fact that they will never demand in situ the services it provides. Society values the existence of range ecosystems or the option value of saving them for use in the future. This benefit of range has not been estimated empirically. To date, this benefit, as well as the benefits from rare and endangered species, have been assured through legislation. Legislation has mandated agencies to provide for ecosystem continuity and diversity as well as to make efforts to insure the survival of limited animal and plant species. Given the present state-of-the-art, demand estimates and marginal values of these benefits are not expected to be forthcoming.

The relation between ecological continuity and other range benefits should be evaluated. Environmental quality may be maintained or improved with proper and moderate livestock grazing

[7]The Bureau of Land Management was at one time going to issue an RFP for such a study; however, to my knowledge, it was never issued.

(Council on Agricultural Science and Technology 1974). In the management and planning of wildlands, program costs should be allocated to the benefits for which they are implemented.

DATA REQUIREMENTS

Although various range benefits have been discussed, past work has been limited almost exclusively to valuing range forage for livestock production. All methods for forage valuation for livestock production require considerable data collection. In comparisons with market-priced forages and feed sources, privately leased forage is the most appropriate forage source. Currently, land appraisers of the USFS and BLM are appraising private lease rates as part of the 1985 Grazing Fee Study required by the Public Rangeland Improvement Act of 1978 (PRIA). This study will be completed in March, 1984 at a cost of $2.8 million. While the 1966 Western Livestock Grazing Survey used mail questionnaires, the appraisal study is attempting complete enumeration of all range forage leases comparable to public rangeland.

In any study of leases, the basis for the lease must be determined. The FS and BLM charge on an AUM basis, but other leases (private and public) are based on acreage, number of head, rate of gain, or animal units as well as AUM's. Even if AUM's are used, the definition from lease to lease is variable. Therefore, the researcher must exercise care to adjust all leases to a common basis for comparison purposes, and to estimate averages.

Services provided by the leasor and leasee also vary. Updates of the 1966 Western Livestock Grazing Survey were based on lease rates alone, assuming factors affecting the lease rate remained constant. The factors affecting the private lease rate must at least be examined periodically. Lease rates are influenced by the value of services provided by the leasee and leasor, the nature of the forage resource, size of the lease, location, term of lease, characteristics of the leasee's livestock operation, and other uses. Grazing leases include various services other than the use of range forage. Those services and their value must be determined to estimate the value of the forage. Services often ignored are range improvements that have been provided by either the leasee or leasor. A record of past improvements or future improvements required by the lease must be obtained in order to determine the annual value of the forage.

Characteristics of the rangeland and forage that influence value include quantity of forage, quality of forage, topography, water supplies and seasonal availability for grazing. Most range scientists feel that quantity and quality of forage must be strong determinants of forage value. However, the many other factors affecting forage value seem to mask these influences. Topography and season of use interact to influence grazing value. Rugged summer range causes increased livestock handling costs, but broken topography on winter ranges provides protection for livestock. Topography also influences suitability of ranges for different types of livestock.

The size, location and term of grazing leases also influences lease rates, and information is required on each. The conditions of the lease may also provide for an option for renewal on the term of the lease.

Many of the above factors interact in the ranch operation. The value of forage from a particular range is dependent on how that resource is incorporated with other resources of the ranch using the forage. Production analysis is required to determine the relationships between the resources to produce livestock. This is usually not done in lease studies, but does influence lease rates. In fact, this probably explains why ranges that are very similar in quality and quantity of forage lease for different amounts and why ranges vastly different in productivity lease for the same rate.

In order to capitalize permit values, those values must be determined through analysis of ranch sales or appraisals. A survey of ranch sales can be made in which the permit value is determined, or land appraisers can be interviewed to determine estimates of land sales (Fowler and Gray 1981). The former is based on examination of actual land sales but is relatively expensive. Also, ranch sales may be few for a particular area and year. Fowler and Gray (1981) interviewed land appraisers in New Mexico, and relied on the appraisers' knowledge of land and permit values rather than actual sales. In addition, the appraisers were asked to assess the values over the past decade which allowed comparison of value trends of different range resources.

Characteristics of the range associated with permit sales may influence permit values. Additional data collection would be needed in surveys of actual ranch sales.

Production analysis methods require the most extensive data collection as range forage is but one input in livestock production. Ranches are sampled and ranch budgets determined. These budgets need to be detailed so that production relationships can be determined. Ranch budgets can then be used to formulate linear programming approximations of the production processes. Information on alternative feed sources, seasonal availability of forage, livestock prices, and range capacities as well as livestock parameters is needed, but it is not evident how these parameters should be manipulated within the linear programming models. A study by a group of scientists should be made that would result in a set of guidelines for using this approach so that values are consistent and comparable between geographical areas and across different groups or individuals that use the technique.

All methods require a sample or complete enumeration of a population, and care must be used in identifying that population and the frame. In addition, appropriate experimental design is

required in sampling, stratification and survey instrument design. Actual surveys have been done by phone, mail, and personal interviews.

Both the appraisal study and the survey of government leasing policies being done by Colorado State University use personal interviews. The quality of data is usually higher with personal interviews, if the interviewers are knowledgeable and well-trained, and clarification of questions is facilitated. In the past, a sample survey has been made of livestock operators; however, many of those sampled did not lease grazing and responded on hearsay knowledge. In addition, enumeration may be required where public land dominates and few private leases exist.

Regardless of what method is used to value forage, revaluation is needed over time. Theoretically it would be possible to do studies annually. But, this is unrealistic due to cost and time constraints. Therefore, some annual updating must be done on indexing basis with complete periodic updating of the value.

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OPPORTUNITIES FOR THE MORE INTENSIVE USE OF INPUT-OUTPUT ANALYSIS IN PUBLIC RANGELAND DECISION-MAKING

Frederick W. Obermiller

ABSTRACT: Numerous opportunities for the more intensive use of input-output methodology in public rangeland and forestland research and decision-making exist. Some of these opportunities, as well as useful and operational extensions of the static methodology, are described. Literature relative to the topic is highlighted.

INTRODUCTION

Input-output analysis essentially is a form of income accounting which has well established roots in macroeconomic theory. The technique has been extensively used, and perhaps almost as extensively misused, in range and forest economics research and related applications. Unfortunately, economists have provided input-output model users and decision-makers with something less than thoughtful guidance in the development, modification, and application of input-output methodology.

This paper addresses some, but by no means all, of the deficiencies in development and application of regional (substate) input-output models. A common theme in the paper is the application of such models to natural resource management and related policy issues, with special emphasis on public rangeland resources. The paper consists of three parts. First, the role of input-output analysis in the issue area is justified. Second, opportunities for more comprehensive use of conventional static models are described. Third, useful operational modifications of existing models are presented. An attempt is made throughout the paper to identify recent literature of relevance, for the topic addressed is far too broad and complex to be treated in depth here.

Frederick W. Obermiller is Associate Professor and Extension Regional Resource Economist in the Department of Agricultural and Resource Economics, Oregon State University. The author acknowledges the helpful review comments provided by John A. "Jack" Edwards, Oregon State University; John M. Fowler, New Mexico State University; John E. Keith, Utah State University; and Giles T. Rafsnider, Colorado State University. The title of the original paper presented at the Range Economics Symposium was "Capturing the Opportunity: An Expanded Role for Input-Output Analysis in Public Land Use Decisions."

JUSTIFYING THE USE OF INPUT-OUTPUT ANALYSIS

The use of input-output models in range and forest economics research, or more generally in natural resource management and policy analysis, has been widespread. Despite the technique's major conceptual and empirical limitations, and despite the reservations expressed by some economists, e.g., Smith and Martin (1972), Dyer (1981), static input-output models remain one of the most widely used--and often abused--techniques in regional economic impact analysis.[1] Further, values derived from input-output models, especially estimates of secondary (indirect and/or induced) income impacts, sometimes are used in project or economic feasibility studies, especially in benefit-cost analysis--to the consternation of some economists and delight of some special interest groups.

In an empirical sense, the static input-output model's major limitation is its data intensity. Questions of statistical error and response bias aside, construction of primary data models--even for relatively small regional economies--may be both time consuming and expensive:[2] an observation used to justify the use of secondary data models by the Forest Service (Alward and Palmer). The alternative approach, typified by the Forest Service IMPLAN system, uses secondary data to develop static models from the national input-output model constructed by the United States Department of Commerce (1979). Such secondary data models are based on highly questionable assumptions (Czmanski and Malizia 1969; Schaffer and Chu 1969; Miernyk 1976) which when tested have been shown to produce regionalized models whose coefficients differ markedly from those

[1] Recent surveys of the extent of use of input-output analysis as applied to natural resource (range and forest) management and use issues are provided by Godfrey (1981), Eppley (1982), and Alward and Palmer, among others. Godfrey, and also Kearl (1980) and Martin (1981) discuss many of the more common misapplications and misuses of the technique, most of which are attributed to the naivety, inexperience, and/or training deficiencies of personnel applying input-output methodology.

[2] In Oregon, for example, county-level primary data models developed over the past two years have, on average, cost approximately \$10,000 - \$12,000 to construct; and have taken about nine months to complete.

revealed using primary data methods for the same or similar regions (Carroll, 1980; Keith, 1982); although Boster and Martin (1972) offer contradictory evidence. These recognized problems notwithstanding, the secondary data approach to construction of static input-output models typically is justified on the basis of the relative efficiency argument in conjunction with agency policy to use uniform data sets in model development and application.[3]

Perhaps more troublesome than empirical constraints and the debate over the veracity of secondary data models are two basic assumptions underlying both the conceptual structure and application of static input-output models. These are: (1) the assumption that all firms in a given sector of the economy produce a single homogeneous output and share a fixed factor proportion production function which is homogeneous of degree one, ruling out external economies or diseconomies, joint products, and multi-product firms; and (2) the assumption that the economy being modeled is in equilibrium, implying that the composition of endogenous demand for a sector's output, relative prices, trading patterns, and technology are all constant (Boyle and Obermiller, 1982). While the second assumption generally applies to the other major techniques--including most forms of linear programming, benefit-cost analysis, and budgeting--used in range and forest economics research, the first assumption places input-output methodology at a singular disadvantage in the valuation of nonmarket resources, the thrust of natural resource economics research over the past decade.

Why, then, are static input-output models so widely applied to problems involving the allocation and development of forest and range resources? Several explanations may exist, but two are paramount. First, input-output models provide a wealth of information on the regional distributive impacts of exogenous disturbances--information generally not provided by econometric or linear programming models, information not contained in the generalized NED (i.e., national perspective) approach to benefit-cost analysis, but information required by the statutes governing the public land use decision-making process (Obermiller and Boyle, 1981; Obermiller, 1982b). Second, the input-output approach is exceedingly postive. The neoclassical assumptions of profit maximization, consumer utility maximization, and resource allocation through perfect markets are not used:

The economy is described as it is rather than as it should be under the imposed structural and behavioral assumptions.[4]

The first of these two explanations gains in importance to the extent that income distribution is, for whatever reason, the crux of the public land use debate and may be in the process of becoming a central problem in applied welfare economics. Following Bromley (1981): "It does very little good to offer as a goal a construct which--for a variety of reasons--cannot produce the answers as to which interests ought to receive the income streams from public lands" (p. 11). And, "...in public land management, there is no unambiguous metric whereby we can know relative values of many of the goods and services which flow from the public lands" (p. 3). Bromley's comments may be interpreted as (1) skeptical of the ultimate success of generalized or idealized benefit-cost analysis (Workman, 1981, pp. 9-16) and hence of at least some nonmarket valuation methodologies (Howitt, 1981, pp. 1-3); while (2) lending support to the use of input-output techniques in range and forest economics research--not that the methodology answers the normative question posed by Bromley, but rather, as noted above, it provides the positive distributive information to be weighted by the decision-maker(s) in formulating his or her social welfare function.[5]

The comparative strengths, or advantages, of input-output analysis invite its more extensive use in public land planning, management, and decision-making. Concurrently, efforts to reconcile primary and secondary approaches to model development and application, and to relax the conceptual limitations underlying the static approach, are warranted. Some of these opportunities are reviewed below.

OPPORTUNITIES FOR EXPANDED USE OF TRADITIONAL REGIONAL MODELS

Possibly the most serious failing of input-output model users is the tendency to concentrate simply on applications of gross output multipliers derived from the Leontief inverse matrix to the exclusion of the wealth of descriptive, and at least casually analytic, information also contained in the transactions and direct coefficients

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[3]In the following discussion, emphasis is placed on the distributive information provided by static input-output models. Keith (1982) notes that such distributive information, if based on coefficients generated from non-survey techniques and secondary data models, may result in gross errors relative to partitive-based analysis using primary data models. The example used in this discussion is a primary data input-output model.

[4]Little, Mishan, Weisbrod, Robbins, Hicks, Chipman and Moore, and others have noted that these assumptions prescribe both behavioral activity and conditions of exchange in a conceptual marketplace, and hence contain implicit value judgments. Thus, when the neoclassical paradigm is used in policy analysis, and/or as a basis for policy recommendations, the construct's arguments are at best conditionally positive, if not entirely normative, in content. An equivalent critique can be made, of course, of any construct. For a review of relevant literature see Obermiller and Wear (1982, pp. 16-28).

[5]A recent survey of this literature is provided by VanKooten (1982). See also Workman, loc cit.

matrices. For example, sectoral and regional net trade balances can be derived from the transactions matrix as in table 1 below (see Obermiller and others 1981). The net trade balance may, in turn, be expressed as a percent of a sector's or the region's value of total gross output--a strong indicator of the extent to which the sector is basic to the economy, and/or factor markets in the regional economy are structurally developed.

Seldom is use made of the direct coefficients, or A, matrix. This is particularly unfortunate because it is within this matrix that the fixed factor proportion production and average cost functions are captured. Drawing from the A matrix, differences in the production and/or cost relationships characterizing, for example, public land dependent ranchers versus nonpermittees in the same region can be compared as in table 2; an significant differences can be subjected to further evaluation. Moreover, the direct coefficients matrix is useful in summarizing both the

Table 1. Value of total output, exports, imports, and net trade balances among sectors of the Baker County, Oregon, economy in 1979.

Sector	Total gross output		Exports & imports		Net trade balance	
	Value ($000)	Percent of total output	Export value ($000)	Import value ($000)	Value ($000)	Percent of total gross output
1. Dependent ranching	12,321	2.7	8,725	1,329	7,396	60.0
2. Other ranching	7,881	1.7	3,226	1,805	1,421	18.0
3. Other agriculture	6,108	1.3	2,277	556	1,721	28.2
4. Food processing	5,710	1.2	2,920	1,025	1,895	33.2
5. Timber harvesting & hauling	8,676	1.9	2,366	1,621	745	8.6
6. Lumber & wood products processing	32,451	7.0	22,021	9,860	12,161	37.5
7. Agricultural services	11,573	2.5	2,874	7,645	-4,771	-41.2
8. Mining & mineral products processing	15,389	3.3	11,348	10,097	1,251	8.1
9. Construction	31,499	6.8	5,503	13,908	-8,405	-26.7
10. Transportation	12,414	2.7	3,411	7,077	-3,666	-29.5
11. Communications & utilities	14,563	3.2	5,518	9,586	-4,068	-27.8
12. Finance, insurance, & real estate	23,953	5.2	4,810	15,676	-10,866	-45.4
13. Automotive sales & services	22,661	4.9	5,447	13,012	-7,565	-33.4
14. Professional services	8,413	1.8	721	2,344	-1,623	-19.3
15. Lodging	2,103	0.5	1,559	283	1,276	60.8
16. Cafes & taverns	7,875	1.7	5,243	1,882	3,361	42.7
17. Wholesale & retail trade	62,847	13.5	6,756	43,856	-37,100	-59.0
18. Other wholesale & retail services	3,425	0.7	100	731	-631	-18.4
19. Households	120,839	26.0	34,251	23,654	10,597	8.8
20. Bureau of Land Management	947	0.2	947	323	624	6.6
21. U.S. Forest Service	21,083	4.5	21,083	16,962	4,121	19.5
22. Local government	22,616	4.9	11,938	4,508	7,430	32.9
23. Local agencies of state & federal government	8,878	1.9	6,905	1,118	5,787	65.2
Subtotal	**464,315**	**100.0**	**169,948**	**188,875**	**-18,927**	**-4.0**
Local investment by nonlocal business	11,859					
Baker County Total	**476,174**					

Table 2. Differences in the production and cost functions of permittees versus other ranchers as reflected in their direct purchasing coefficients, Baker County, Oregon, 1979.

Sector from which purchases are made	Direct purchasing coefficients: Permittees	Nonpermittees	Permittees as % of nonpermittees
1. Dependent ranching	.05923	.06129	97
2. Other ranching	.05826	.07150	81
3. Other agriculture	.01919	.02149	89
4. Food processing	.03560	.02410	148
5. Timber harvesting & hauling	0	0	---
6. Lumber & wood products processing	0	0	---
7. Agricultural services	.10982	.11491	96
8. Mining & mineral products processing	0	0	---
9. Construction	0	0	---
10. Transportation	.03095	.01263	245
11. Communications & utilities	.01189	.01203	99
12. Finance, insurance, & real estate	.13046	.11849	110
13. Automotive sales & service	.00030	0	NA
14. Professional services	.00787	.00196	402
15. Lodging	0	0	---
16. Cafes & taverns	0	0	---
17. Wholesale & retail trade	.07954	.08768	91
18. Other wholesale & retail services	0	.00005	NA
19. Households	.20583	.17630	117
20. Bureau of Land Management	0	0	---
21. U.S. Forest Service	0	0	---
22. Local government	.02448	.01677	146
23. Local agencies of state & federal government	0	.00038	NA
Subtotal - All Local Sectors	.77342	.71957	107
24. Nonlocal households	0	.00004	NA
25. Nonlocal government	.02949	.02927	101
26. Nonlocal business	.07816	.19990	39
Subtotal - All Nonlocal Sectors	.10765	.22921	47
27. Inventory depletion	.06519	0	NA
28. Depreciation	.05179	.05221	99
TOTAL - ALL SECTORS	.99805	1.00100	NA

dependency of various sectors on local suppliers, and the extent to which each such sector generates value-added through purchases from local households, as in table 3.

The transactions and Leontief inverse matrices can be used in tandem to describe the final contribution of each local sector to a region's economy, taking into account both its final demand sales and its degree of interdependency with other local sectors. These calculations are especially useful when compared with initial sectoral contributions to local economic activity as in column two of table 1. For example, the calculations appearing in table 4 show that, in Baker County, Oregon, the actual contribution of all ranching to total value of gross local output was 9.5 percent in 1979, not 4.4 percent as might have been concluded from a cursory reading of the transactions table alone.

Input-output models commonly are applied to a direct or extrapolated change in value of livestock or wood product exports attributable to a public land management agency action.[6] Too often, the corresponding impact on total gross business activity and/or total household income is calculated, but the distribution of those income effects among local sectors and local households--one of the two major strengths of the technique--

[6]These applications are a routine part of the environmental impact statements prepared by the Bureau of Land Management and Forest Service. Other published applications frequently referenced in the literature on the subject include Bromley and others (1968); Bartlett and others (1979); and Torell and others (1980).

Table 3.--Percentages of total purchases from all local sources and from local households by sector of the Baker County, Oregon, economy in 1979.

Sector	Percent of total purchases from all local sectors	Percent of total purchases from local households
1. Dependent ranching	77	21
2. Other ranching	72	18
3. Other agriculture	84	18
4. Food processing	81	12
5. Timber harvesting & hauling	69	25
6. Lumber & wood products processing	44	24
7. Agricultural services	32	15
8. Mining & mineral products processing	31	26
9. Construction	54	21
10. Transportation	40	14
11. Communications & utilities	32	26
12. Finance, insurance, & real estate	34	29
13. Automotive sales & service	40	21
14. Professional services	69	55
15. Lodging	77	36
16. Cafes & taverns	73	32
17. Wholesale & retail trade	28	14
18. Other wholesale & retail services	75	45
19. Households	80	1
20. Bureau of Land Management	66	58
21. U.S. Forest Service	19	10
22. Local government	80	42
23. Local agencies of state & federal government	87	79
BAKER COUNTY TOTAL	56	20

is ignored. As is seen in table 5, an initial $400,000 decline in exports by the dependent ranching sector would have resulted in about a one million dollar decrease in value of local business activity, of which about $191,000 would have been foregone income to local households (value-added). Of this amount, 46 percent or $87,600 would have been lost income to dependent ranch households, an estimate obtained by multiplying the direct loss ($81,808) by the appropriate diagonal value from the Leontief inverse matrix. The remaining $103,200, or 54 percent of foregone household income, would have been lost by Baker County households not directly involved in public land dependent ranching--a measure that helps explain the degree of local community interest in public land use decisions.

Although it is infrequently done, values such as these may be accurately depicted in a number of ways.[7] In the present example, the change in value of livestock exports was simulated, using primary data, based on a proposed reduction of 10,589 AUMs of public grazing. From the viewpoint of county-wide business activity, the proposed grazing reduction would have resulted in a gross revenue loss of $102 per AUM, or $40 per AUM to the dependent ranching sector alone. Net (household or value-added) losses would have been $18 per AUM county-wide, or $8.27 per AUM to affected permittees. Deducting labor, management permittee-financed allotment improvements, and applicable noncash costs from the $8.27 estimate would yield the derived average value of an AUM o public land forage to Baker County permittees--an operational alternative to the present method of establishing grazing fees (Obermiller and McCarl 1982). Capitalization of that residual value and the $8.27 estimate would bracket the average permit value in Baker County, and capitalization als could be used to extrapolate the sectoral or regional opportunity costs of public grazing or timber harvest reductions (Obermiller 1980a).

Still other applications of static models, applications requiring no further revision of existing models, are feasible. While the example employed above is negative in the sense that the initial stimulus is a proposed reduction in federal grazing, the same approach can be, and has been, used in analyzing the income effects of increased grazing or timber harvest. As in the instance of AUM reductions, increases in export sales of

[7]For a related application to forest use issues, specifically wilderness area additions, see Obermiller (1980b).

Table 4.--Contribution of final demand sales by each sector of the Baker County, Oregon, economy to total county business activity in 1979.

Sector	Value of final demand sales ($000)	Business income multipliers (Type II)	Value of direct & indirect business activity ($000)	Percent total county business activity
1. Dependent ranching	10,622	2.73	28,998	6.33
2. Other ranching	5,636	2.59	14,597	3.18
3. Other agriculture	2,389	2.73	6,500	1.42
4. Food processing	2,920	3.08	8,994	1.96
5. Timber harvesting & hauling	2,366	2.55	6,033	1.32
6. Lumber & wood products processing	31,799	2.11	67,096	14.63
7. Agricultural services	4,621	1.75	8,087	1.76
8. Mining & mineral products processing	12,797	1.77	22,651	4.94
9. Construction	14,691	2.20	32,320	7.05
10. Transportation	3,461	1.84	6,368	1.39
11. Communications & utilities	5,551	1.77	9,825	2.14
12. Finance, insurance, & real estate	6,745	1.83	12,343	2.69
13. Automotive sales & service	7,062	1.87	13,206	2.88
14. Professional services	940	2.65	2,491	0.54
15. Lodging	1,559	2.68	4,178	0.91
16. Cafes & taverns	5,255	2.78	14,609	3.19
17. Wholesale & retail trade	8,547	1.64	14,017	3.06
18. Other wholesale & retail services	124	2.76	342	0.01
19. Households	37,412	2.52	94,278	20.56
20. Bureau of Land Management	947	2.61	2,472	0.54
21. U.S. Forest Service	21,083	1.51	31,835	6.94
22. Local government	11,938	2.93	34,978	7.63
23. Local agencies of state & federal government	6,974	3.19	22,247	4.85
BAKER COUNTY TOTAL[1]	205,430	2.26	464,315	100.00

[1]The reported totals are correct but may not equal column sums due to rounding error.

livestock or forest products corresponding to increases in primary input supplies must be extrapolated.

The models are amenable to tradeoff analysis as, for example, in evaluating the relative distributive impacts of changes in recreational vis-a-vis livestock grazing land uses at the regional level, or similarly the extent to which income gains attributable to improved riparian and/or wildlife habitat offset losses caused by AUM or allowable cut reductions. Such applications are especially useful when making public land allocation decisions for they provide information on the relative primary and secondary income impacts of alternative use allocations--valued using a consistent methodological framework.

Clearly, applications of existing, unmodified, static input-output models to forest and rangeland resource issues are manifold. Only a few have been mentioned. The failure of model users to exploit these potentials, while understandable given the training and background of typical users, does considerably less than full justice to what Drucker (1981) has called "...one of the most advanced tools of modern economics, input-output analysis" (p.5).

OPERATIONAL MODIFICATIONS OF POTENTIAL VALUE

A strong case can be made for assignment of top priority to more thorough use of unmodified static models; and of secondary priority to reconciliation of the primary versus secondary approaches to model development. Modifications designed to redress some or all of the conceptual limiations underlying the static model would be useful, but in many instances operational modifications may be long in coming. There are certain exceptions, however, three of which are summarized below. Each has been empirically implemented and found to be useful in assessing the regional economic impacts of public land use alternatives.

Table 5.--Initial and final gross income effects on Baker County economic sectors resulting from a $397,453 loss in gross revenue to dependent ranchers.

Sector from which purchases are made	Direct coefficient	First round spending impact (loss in $)	Direct and indirect coefficient	Final gross income effect (loss in $)
1. Dependent ranching	.05923	23,451	1.07071	425,557
2. Other ranching	.05826	23,156	.07468	29,682
3. Other agriculture	.01919	7,627	.04962	19,722
4. Food processing	.03560	14,149	.04676	18,585
5. Timber harvesting & hauling	0	0	.00086	342
6. Lumber & wood products processing	0	0	.00245	974
7. Agricultural services	.10982	43,648	.15001	59,622
8. Mining & mineral products processing	0	0	.00738	2,933
9. Construction	0	0	.05525	21,959
10. Transportation	.03095	12,301	.06678	26,542
11. Communications & utilities	.01189	4,726	.04814	19,133
12. Finance, insurance, & real estate	.13046	51,852	.20507	81,506
13. Automotive sales & service	.00030	119	.05437	21,610
14. Professional services	.00787	3,128	.03573	14,201
15. Lodging	0	0	.00188	747
16. Cafes & taverns	0	0	.01015	4,034
17. Wholesale & retail trade	.07954	31,613	.29190	116,017
18. Other wholesale & retail services	0	0	.01494	5,938
19. Households	.20583	81,808	.48006	190,801
20. Bureau of Land Management[1]	0	0	0	0
21. U.S. Forest Service	0	0	0	0
22. Local government	.02448	9,730	.05409	21,498
23. Local agencies of state & federal government	0	0	.00544	2,162
Subtotal - All Local Sectors	.77342	307,398	2.72627	1,083,565
24. Nonlocal households	0	0		
25. Nonlocal government	.02949	11,721		
26. Nonlocal business	.07816	31,065		
Subtotal - All Nonlocal Sectors	.10765	42,786		
27. Inventory depletion	.06519	25,910		
28. Depreciation	.05179	20,584		
TOTAL - ALL SECTORS[2]	.99805	396,678		

[1]Grazing fees paid by permittees are treated as import purchases since these funds are returned directly to the Federal Treasury and do not directly influence the operating budget of the Bureau of Land Management's Baker District.

[2]Does not sum to 1.00000 and $397,453 due to rounding error.

Two address elements of the second basic assumption underlying static models: equilibrium and constant trading patterns. The third modification uses the forward linkages revealed in the sales patterns of existing economic sectors to distribute the output effects of an initial change in primary industry supply; and thereby allows the user to address the supply side influences of public land use changes in a more straightforward manner.

The temporal pattern of exogenous disturbances in product (e.g., feeder cattle and wood product) markets as well as in public land "factor markets," and the temporal response by endogenous local sectors to those disturbances, is a significant question in economic impact analysis--but one which the static input-output model cannot address. To more fully appreciate, understand, and evaluate these temporal relationships Johnson (1979) developed and applied a dynamic intersectoral model using primary data, as summarized

elsewhere by Johnson and Obermiller (1982).[8] The dynamic model was successfully applied to a variety of scenarios involving changes in allowable cut on the Malheur National Forest in northeast Oregon, giving particular useful information on the temporal distribution of secondary income changes attributable to cyclical sales by the local wood products industry to final demand. For all sectors of the local economy, dynamic multipliers were found to be higher in value than comparable static multipliers due to the internalization of the accelerator effect. The implication is that conventional applications of static models underestimate the cumulative regional impact of changes in public land policy and/or other exogenous influences. In essence, static models fail to fully account for the regional income effects of land use decisions affecting levels and rates of investment and disinvestment.

Boyle (1981) and Boyle and Obermiller (1982) developed and implemented a method to relax the assumption of constant trading patterns. Their technique is applicable not only to questions of economic growth, i.e., the appearance of new industry or disappearance of existing industry, but also to issues of technological and hence trading pattern change within existing sectors stemming from public land management or use decisions. Minimal data beyond that required for the construction of the conventional static model are needed. The method is of high operational value for two reasons. First, it prolongs the useful life of existing models. Second, it allows input-output and linear programming models to be merged in an analytic construct consistent with the initially incompatible production and cost function relationships underlying the two algorithms.

While conventional static models are applied to changes in final demand, and operate through systems of backward linkages (purchasing patterns), the same models also describe the forward linkages (selling patterns) extant in the regional economy. Epply (1982) used these forward linkages to distribute the output effects induced by an initial change in primary input supply. The conventional demand pull model, with appropriately adjusted technical coefficients, then was used to estimate the final income effects of changes in forage and timber availablilities on public lands. Further refinement of the technique is underway, and additional documentation soon will be forthcoming. The value of her technique is its direct applicability to issues involving changes in the quantity (or price) of inputs controlled by public land management agencies--in contrast to the awkward and quite often inconsistent procedures utilized when extrapolating changes in final demand sales from corresponding changes in natural resource availabilities.

[8]In addition to standard static model data, the operational dynamic model uses capital-output coefficients, excess capacity measures, depreciation rates, desired capacity levels, and various lag parameters. See Obermiller (1982a).

SUMMARY

All three modifications summarized above relax some, but by no means all, of the conceptual limitations underlying static input-output models. None may be as important, or as relevant to sound natural resource management and policy formulation, as more comprehensive and insightful use of conventional static models. To the extent that public land income distribution concerns may be of increasing importance to society, and thus of increasing interest to resource economists and related professionals, it is at least possible that input-output analysis may advance from a supporting to a leading role in future public land planning, management, and decision-making.

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SMALL REGION INPUT-OUTPUT MODELS:

SOME OBSERVATIONS AND RESERVATIONS

John E. Keith

ABSTRACT: The adoption of non-survey input-output techniques by public land management agencies may cause significant errors in impact estimation. A review of current literature indicates that non-survey techniques can lead to errors if the economic sector of interest is not representative or is highly aggregated. Research into these problems should focus on survey and hybrid I/O tables compared to the non-survey tables.

INTRODUCTION

The use of regionalized input-output (I-O) models for analytical and policy purposes by now is a relatively "old" economic technique [see Jensen and Macdonald (1982) for a bibliography]. Within the past five years it has become an institutionalized process in the major land management agencies, particularly in the Forest Service and Bureau of Land Management (BLM). The regional economic analyses using the Forest Services' IMPLAN system (Alward and Palmer, no date) are based on regionalized I-O tables, and these models are more or less recognized as the appropriate tools for the assessment of the regional impacts of public policy. Some states have readily adopted I-O models in their planning (Washington and Alaska, for example) others have not (Utah) and some have utilized several methods (such as Idaho). As regional I-O analysis becomes more widely used, particularly by individuals who have little or no appreciation for either the limitations of the technique or the criticisms which have been voiced among professional economists, it seems appropriate to review the literature and focus on both problems and research needs associated with the kind of regionalized I-O models to which the agencies are becoming committed.

THE THEORETICAL FOUNDATIONS

An I-O table is a set of deterministic linear homogenous fixed-coefficient production functions which relate a unit of output to input requirements in terms of a monetary numeraire for an assumably homogenous set of firms. Since it is obvious that few firms are homogenous, the stochastic nature of aggregated transactions and/or coefficients is disregarded. The issue has been discussed rather widely in the literature (e.g. Hurwicz, 1955; and Gerking, 1979) but the generation of confidence intervals around I-O results is infrequent. These functions preclude substitution among the various inputs to production. Thus, for a given public policy, such as a reduction in AUM's, the accompanying proportional change in livestock sales will be distributed among the inputs according to the direct purchasing coefficients.

Many analyses relate reductions in the use of public resources to final sales using methods which allow input (forage or stumpage) substitution. These frequently are optimization approaches. The theoretical problem is clear. If input purchases change in sectoral composition, so must the I-O table; yet, recalculation and rebalancing of the tables is seldom done. For example, if public land grazing is replaced by the purchase of feed grains and alfalfa, a significant shift among the sectoral purchases is indicated. In many Western livestock operations, use of other inputs, such as fertilizers, might also be affected. How crucial the differences are with respect to projecting regional economic changes is unknown at present and would depend substantially on the structure of the relevant economy, particularly the agricultural sectors. Cross-sectional studies should be undertaken to examine this problem.

A second related issue also is important. The I-O framework, if used to forecast long-term regional effects of public policy, is likely to be incorrect. The I-O is a static model, and as such represents the economy at a point in time. As Miernyk (1966) has suggested, long-term projections require a dynamic model incorporating adjustments to changing relative prices and/or technology.

Some research has been undertaken to dynamicize I-O models but the current agency practice utilizes the static approach. Miernyk (1970a and 1970b) and Bargur (1969) utilized a capital formation approach in order to examine total output changes as a region grows. These models are theoretically relatively simple in that they consist of an augmented matrix of capital coefficients, but they are quite data intensive. In these models, the definition of the "capacity" to output relationship is a difficult problem. Further, they do not address labor markets, economies of scale, or technological advances which affect the capital-output ratios for an industry (Richardson 1972).

An alternative approach in which local market supply functions are used has been studied by Hudson and Jorgenson (1974 and 1976) and Liew and Liew (1980 and 1981). These approaches estimate coefficient changes from market price projections using the dual of a truncated translog production function. The conditions under which the translog production function has a unique associated dual cost function are somewhat restrictive but the approach does allow for relatively sophisticated

John E. Keith is an Associate Professor of Economics at Utah State University in Logan, Utah.

forecasting of coefficient change based on market behavior.

The extent to which the static models generate errors has not been studied extensively, although Polenske (1970) suggests that dynamic models may not be a significant improvement. It is possible that for some applications the static model is a reasonable one, while other situations require a dynamic approach. A broad-based longitudinal study of I-O forecasts and actual changes would be desireable, as would the development of requirements for a relatively simple dynamization routine. Clearly, the more changes expected in a region, the more imperative is the inclusion of structural change.

A third problem in regional I-O analysis is the introduction of new industries or the failure of an old one, both common phenomena in the Intermountain West. The major consideration, other than the identification of regional purchases information, is the adjustment of coefficients to reflect import substitution (sectoral sales) (Lewis and others 1977; Glover and others 1981; Boyle and Obermiller 1982). Although data intensive additions or deletions are not theoretically difficult, if projections are based on infant industries, such as synfuels, transactions data may be wild guesses at best.

A final problem in the utilization of I-O techniques is the interpretation of the various multipliers generated. These multipliers have attracted considerable attention among the agencies and other users of I-O results. Unfortunately, these multipliers have often been misinterpreted and misused. This misuse is as much a problem of the lack of clear definition by economists as misunderstanding by the lay users. It might be more appropriate for all multipliers to be expressed relative to a given parameter, such as final demand, rather than each different parameter. The development of the Type III multiplier, which includes increases in leakages from household consumption, has been a definite improvement, although its planning use appears confined to professionals. Since there have already been some calls for redefinitions of these multipliers (West and Jensen 1980), a thorough review of their use and taxonomy might be beneficial to practitioners.

REGIONALIZING TABLES

Developing regional models entails several difficulties. First, the appropriate region for which the table is to be constructed must be selected. Any designation, from county to multi-state, is appropriate depending upon the purpose of the analysis. In general, the smaller the region, the less likely it is to be self-sufficient and the more important the role which imported inputs play. Judgment is crucial to this choice. The larger the area the more likely it is that secondary data sources will be plentiful, but the larger will be the data requirements for the I-O table. However, most professional economists attempt to include within the bounds of the region the major trading areas for which impacts may be significant. For grazing policy, local agriculture, feed, and livestock marketing areas are of primary importance. For lumbering, the labor market and lumber mills might establish the appropriate region. The development of a consistent set of agency guidelines for establishing regions appears to be a fruitful area of research. Given the way in which the IMPLAN system is currently used, one Forest Service or BLM district's economic impact analysis may differ from anothers solely because of the regional designation (see, for example, the BLM Shoshone District Draft and Final Shoshone Grazing Environmental Impact Statements and Comments).

Second, regionalization can be accomplished using survey (primary) data collection or various reduction techniques applied to national (or state) coefficients. It is the general consensus that the survey techniques (primary data) provide the "best" regional tables (Jensen and Macdonald 1982). The data are specific to the region, so that anomolies in specific industries' technologies (partitive description) are included. Further, the region's total interdependence (holistic description) is also based on actual conditions. However, surveys are very expensive and time consuming.

There are two alternatives to survey-based tables: strictly non-survey techniques and hybrid techniques. For the non-survey techniques, the coefficients reference tables (usually national) are adjusted based on the ability of the local industries to supply inputs, using location quotients, local requirement to production relationships, employment ratios, or other ratios of local to national output (Richardson 1972 - Chapter 10). The criticisms of non-survey techniques are directed primarily at the accuracy of these tables in representing a local economy.

There are reasons to believe that for some sectors, at least, local industries may differ significantly from national norms with respect to the technology which they employ. These differences may be the result of the rate of adoption of advances in technology, local market conditions in which relative prices lead to alternative combinations of inputs, or the existence of a distinct type of regional industry which is not included separately in the national sectoral definitions. The latter is a case of the aggregation of firms into an industry definition. Aggregation of sectors is also often done at the regional level. These aggregations may lead to distortions in the coefficients of the regional table. Whether or not these distortions result in significantly differing projections is not clear.

Doeksen and Little (1968) and Hewings (1971) have shown that aggregation does not bias results from disaggregated models as long as the aggregation does not include the sectors in which final demands change. Katz and Burfond (1981) conclude, however, that aggregation of the industries whose effects are being analyzed does lead to different multipliers than disaggregated analysis would generate. Regional economists, in general, are reluctant to endorse aggregations of those sectors for which changes in final demands are postulated. It should be noted that "hybrid" tables, constructed by

using available secondary data, primary data where appropriate and feasible, and national coefficients to "fill in" data gaps, have been recommended by some researchers as the only acceptable alternative to survey tables (Jensen and Macdonald 1982). To date, there have been few studies comparing the survey, non-survey, and hybrid techniques with respect to their results.

Boster and Martin (1972), using a survey-based Colorado River Basin Study (Udis 1967) and a non-survey produced regional table from the State of Arizona I-O table, applied non-parametric statistical analysis to examine differences in coefficients and multipliers. Their conclusion was that, for holistic results, little evidence of significant differences existed, although for the coefficients some significant differences were in evidence. On the other hand, there are several studies (Burford and Katz, 1981; Drake 1976; and Stevens and Trainer, 1976) which disagree as to the effect of coefficient variation on holistic projections and multipliers. Rigorous studies of the effects of coefficient variations due to survey and non-survey techniques, along with their effects on the analytical results, are definitely needed, particularly in light of agency adoption of the non-survey techniques for policy analysis. If the agencies are utilizing absolute, rather than relative, output from the models, as would be the case for a benefit-cost analysis which included secondary economic effects, then some idea of the accuracy of the I-O models and results is crucial.

Interestingly enough, there have been no criteria developed on which to judge which tables are "better". Most studies have assumed that survey data yields the most accurate tables, but the uncertainty and averaging associated with survey data may cause that assumption to be incorrect. National I-O tables involve the same assumptions. Those SIC sectors which are less detailed, such as the agricultural sectors, may involve significant variability in production techniques. It appears that longitudinal studies of actual impacts compared to the projected impacts could yield some criteria on which to judge these I-O processes.

APPLICATION OF I-O TO GRAZING

Given that the non-survey approach appears to be the dominate regionalization technique in the agencies, an examination of its application to grazing policy impacts is of interest. Insofar as range livestock is concerned, the national sector which is used is an aggregate of all meat livestock production in the U.S. The purchases of inputs by Western ranchers are likely different from those of beef or lamb production in the Midwest or South. In fact, the latter two regions make up a sufficiently large portion of the livestock industry that it is probable that the national or average livestock sector is significantly different from that of the Western region.

While the precise regions are different, some interesting comparisons can be made among several regional I-O tables for the Intermountain region. Table 1 presents a comparison of some of the livestock sector coefficients (greater than .005) for Millard County, Utah, (produced by the IMPLAN model), White Pine and Lincoln Counties, Nevada, (produced by the Forest Service Region 4 model), Southeastern, Utah, (produced from a location-quotient reduction of the State of Utah I-O table [Bradley and Fjelsted 1975]), and a range livestock sector for the Upper Main Stem of the Colorado River Basin (produced with a survey approach by Udis 1967). The first two non-survey tables are based on a 1972 national table; the third, on a 1965 Utah table updated to 1972 using secondary data sources for in-state sales by sector. The data for the Udis model was collected in the earl[y] 1960's.

Table 1.--Selected technical column coefficients for the livestock sector

	Millard County	White Pine and Lincoln County	Southeast Utah	Uppe[r] Main Stem
Livestock	.29	.28	.186	[1].16[illegible]
All other Agriculture (including Food and Feed Grains)	.283	.199	.124	.08[illegible]
Wholesale and Retail	.032	.005	.041	.03[illegible]
Fire[2]	.019	.004	.008	.04[illegible]
Transportation	.007	.003	.017	.02[illegible]

[1] Includes a weighted average of range and feeder livestock effects.

[2] Financial, insurance, and real estate.

From a partitive aspect there are wide differences in the tables for each area, particularly in the more significant livestock input sectors. These differences could be explained on the basis of dissimilar regional economies; yet each of the regions is an agriculturally based, particularly livestock-oriented, area with a limited diversity. If anything, the Upper Main Stem area is more diverse than the other regions. Further, note that many of the coefficients presented by Obermiller (1982) for non-dependent operators are quite different than those for dependent operations in a single region (Baker County, Oregon). Given that the IMPLAN uses a national aggregate for the livestock industry, the problem is clear.

Table 2 lists the livestock sector multipliers which are generated from each of the four tables. The holistic results appear to be reasonably consistent for the three non-survey models, although the results from the regionalized State of Utah tables are somewhat lower than those from the national tables. However the survey-based model

Table 2.--Multipliers for the livestock sector

	Output		Income	
	Type I	Type II	Type I	Type II
Millard County	2.27	2.59	3.7	4.83
White Pine and Lincoln County	1.95	2.40	3.3	4.3
Southeast Utah	1.82	2.27	2.80	4.01
Upper Main Stem	[1]1.30			

[1]Range livestock only; feeder livestock multiplier was 2.3, most of which was based on purchase of local range livestock as inputs.

generates a considerably lower Type I multiplier for the range livestock sector. The gross output multiplier using a weighted average of the range and feeder livestock sectors is 1.46.

These comparisons suggest two conclusions. First, the partitive coefficients may vary widely among alternative approaches and data bases. Second, the holistic results (multipliers) may be reasonably consistent for approaches using similar data bases, but may be quite different for survey and non-survey techniques.

A possible explanation for the differences in livestock multipliers lies in the relationship between the purchases of feed and feed grains in other regions (Midwest and South) and the integration of feed production into the livestock operations in the Intermountain West. The aggregation which is reasonable at the national level may not be representative at the local level. The IMPLAN results for grazing policy are likely biased, since the sector of interest is an aggregate one. Range livestock operations use many of their purchased inputs to produce joint products (feeds and livestock), and feed crops are "marketed" through the livestock. These kinds of vertically integrated production processes would be captured by survey approaches.

At the <u>very</u> least, then, an examination of the input use and transactions of Western industries which are affected by public land policy should be undertaken. If these industries appear to significantly differ from the national industries, a hybrid model should be developed by the agencies. Further, survey-based, non-survey-based, and hybrid tables should be developed for selected regions in order to assess the reliability of each. Nationwide adoption of the IMPLAN system in its present form should receive a critical evaluation.

OTHER IMPACT ASSESSMENT APPROACHES

As previously mentioned, several states have opted for alternatives to I-O analysis. Some have used regional econometric models and others have used more or less sophisticated export-base approaches [such as Utah's UPED model (Bigler and others 1972)]. It would seem reasonable to assess the accuracy and efficacy of these models as opposed to I-O analysis, particularly when a specific analytical approach is adopted nationally as is the IMPLAN system. Longitudinal studies of projection accuracies relative to cost of development should be examined. Given that the closer coordination of state and federal policy continues, some reconciliation of these approaches should be attempted.

SUMMARY AND CONCLUSIONS

Several areas of theoretical and empirical research needs have been identified in the literature. Among the more crucial are the assessment of the value and accuracy of survey and non-survey techniques in table preparation, impact projections and policy analysis, the dynamicization of I-O tables in rapidly changing regions, comparisons of I-O and alternative techniques for policy use particularly with respect to accuracy of projections, and the development of consistent criteria for selecting regions to be modeled. In particular, the Western range livestock and other public resource dependent sectors should be examined for differences in technical coefficients among IMPLAN, survey, and hybrid models to more accurately reflect the affects of policy.

The use of IMPLAN and other non-survey I-O tables for both impact analysis and policy planning may have had some negative effects. It is not clear that regional economic analysis has had much impact on policy decisions with respect to grazing for three reasons. First, it is seldom that proposed actions have a significant effect (5 percent change) on total regional output or value added. Second, land managers may not necessarily regard economic impacts as important relative to the biological integrity of resource areas. Third, economic impacts at the regional level are not specified as an economic decision criteria in Forest Service and BLM policy (only national net benefits, i.e., economic efficiency is to be a decision variable). Results from I-O analysis appear to have exacerbated antagonisms among ranchers, managers, and other groups partially because the results reflect potential income transfers more clearly than efficiency gains.

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INTERFACING PHYSICAL DATA AND ECONOMICS

Warren P. Clary

ABSTRACT: Inaccurate physical data or data assumptions can completely invalidate the best economic analysis. Existing field data are used to illustrate the potential impact of data variations on simple economic analyses. Lack of a uniform range forage unit and the need for multiproduct management on rangelands also are discussed.

INTRODUCTION

This discussion is presented from the viewpoint of a non-economist who has had periodic associations with economists. Such associations have made me aware of some of the potential uses of physical data in at least the simpler forms of economic analysis. The accuracy of the data utilized can greatly effect the analysis outcome--simply arriving at the correct economic assumption does not guarantee the correct economic answer. Likewise, assuming a consistent dominant use on a particular piece of land does not guarantee the most efficient land use.

Four information areas will be covered which appear to be often consciously or unconsciously overlooked by those dealing with economic analyses of rangeland activities. These are (1) statistical sampling errors in the physical data, (2) differences in site productivity, (3) lack of a uniform product, and (4) apparent lack of consideration for maximizing land output considering several products or uses.

STATISTICAL SAMPLING ERRORS

The possibility of major sampling errors in the physical data is often ignored or disregarded based on the feeling that "it's the best we have." Perhaps, however, we should examine the possibility that the best sometimes is not good enough, and that bad information can be more harmful than no information at all.

What magnitude of error is likely to occur in field data? The kind of sampling effort which can be made greatly affects the answer (Baker 1957, Ostle 1957). Several typical examples illustrate the possibilities. The minimum number of site analysis transects per chaining project on National Forests is normally one (1) if conditions are reasonably uniform. This minimum of one is not regularly exceeded because of personnel limitations. What magnitude of error can we expect using a single sample site per chaining project?

Suppose an unchained Utah pinyon-juniper stand had a true population mean of 60 lb of herbaceous plants per acre, with a standard deviation of 52 lb/acre. Although these true population values would never be known in practice, using this hypothetical case can illustrate the sampling problem. The mean and standard deviation are not unreasonable because they were actually obtained as sample estimates of some unknown population values. If the true unknown mean were 60 lb/acre, we would find that 20 percent of the time our single transect would yield a value either near zero or greater than 127 lb/acre. Further, suppose that an adjacent chained area had a herbage production mean of 694 lb/acre with a standard deviation of 234 lb/acre. Again, these values would not be known to an investigator, but nevertheless would control the results of our sampling. If we sampled with a single transect, we would find that 20 percent of the time the sample value would be either below 394 lb/acre or above 994 lb/acre. This would be the case even though the true population mean was 694 lb/acre.

If we were to compare the forage yields from these adjacent chained and unchained areas to assess the economic benefits from chaining, what effect would the sample variation have on a simple B/C analysis of the chaining project? A considerable difference in possible results appears when a comparison is made of the gain in forage (assume for simplicity, all herbaceous growth is forage) versus the cost to obtain the gain. If the lowest sample value before chaining and the highest sample value after chaining appear in our comparison then the apparent gain in forage is 994 lb/acre. If the opposite extremes occur together then the estimate of gain due to chaining would be only 267 lb/acre.

Now, let's say a current typical cost of double-chaining with seeding is $30 per acre, the present net worth of an increase of one animal unit month (AUM = amount of forage required per month by a 1,000 lb ruminant animal) is $60, utilization rate is 50 percent, and forage required per AUM is 720 lb. The B/C ratio could vary from 1.4 to about 0.4. Thus, the potential interpretations could range from one of a very successful project to one of near failure simply because of variation among small samples.

The benefits of larger sample sizes can be seen in figure 1. The value limits needed to include 80 percent of the sample means come closer to the true population mean (which is normally unknown)

Warren P. Clary is Principal Range Scientist at the Shrub Sciences Laboratory, Provo, Utah, a unit of the Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

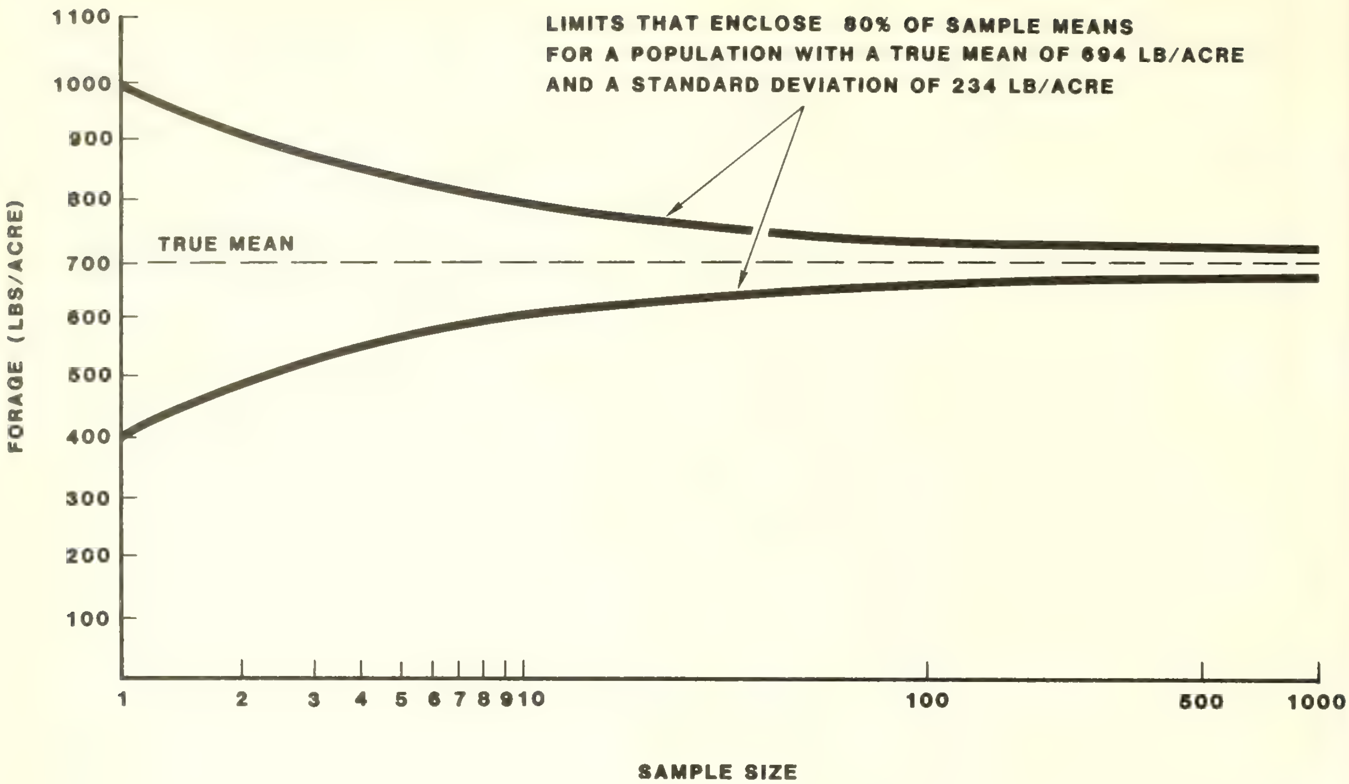

Figure 1.--Relationship between sample size and variation of sample means.

as the size of sample contributing to the sample mean increases. The benefits of increasing the sample size noticeably decrease the sample variability. As the sample size becomes substantial, very large additional sampling efforts are required to produce further meaningful increases in sampling precision. For example, if the sample size is increased from 1 to 10, the variability among sample estimates is greatly reduced, giving B/C ratio estimates of 1.0 to 0.7. These estimates are sufficiently stable to provide usable information for those needing it.

DIFFERENCES IN SITE PRODUCTIVITY

Available data suggest that the variance in herbage production among years is likely to be of the same magnitude as that among sample sites (Clary 1971). Thus, analyses based on only 1 year of posttreatment data are subject to the same potential problems as are within year data based on only one sample site.

An obvious practical approach to solving the problem is to accumulate information from a number of projects and develop average values to be generally applied. This probably is sufficient to provide broad guidelines. When applying these general figures to specific situations, however, we can again greatly miss the mark. Another example is taken from Arizona where annual production of grasses varied from 419 to 2,617 lb/acre among different pinyon-juniper sites (study described in Clary and Jameson 1981). Any general figure applied to these individual sites would have little meaning. Because all of the Arizona sites, but two, could probably be treated at a similar cost, the calculated B/C ratios among the remaining sites would vary from 3.4 on an extremely responsive site to only 0.2 on an unproductive site. Thus, generalized figures applied to a variety of sites can and almost certainly will result in misleading information.

LACK OF A UNIFORM PRODUCT

As I understand it, most approaches used to determine product values rest on the concept that all units of a product have equal value and should receive an equal market price under full competitive market conditions. The FRES or Forest-Range Environmental Study conducted in the early 1970's and the initial analyses conducted by the Forest Service during the mid- and late 1970's in response to the Forest and Rangeland Renewable Resources Planning Act (RPA), both assumed that AUM's were equivalent nationwide. This allowed a rather straightforward linear programming solution to determine where in the nation increases in AUM's of grazing could be developed at the least cost. However, the question of equality of AUM's does not seem to have been formally addressed. I doubt if anyone would be surprised at the suggestion that forage on the same site has different levels of value to the grazing animal at different times of the year or that at the same time of year different locations may have forages of different values (Plath 1957).

One example of this comes from a comparison of beef gain potentials on cool semiarid pine forest ranges in north-central Arizona and subtropical pine forest ranges in central Louisiana (Clary and Grelen 1978). These two areas have several similarities. Both are typified by open pine forest stands with grassy understories, and both historically have been important cattle grazing areas. The forage production after removal of trees is about double in Louisiana compared to Arizona. Thus, analyses based on estimated AUM's of grazing would show about double the value per acre in Louisiana compared to Arizona. However, reduced protein content and digestibility of the native southern forages result in the actual beef gains per acre being roughly equivalent for the two areas. Thus, presumably, the potential grazing rental value of the two areas would be approximately equivalent per acre--not differing by a factor of two based on AUM's of forage.

Interactions of forage quality and season also often occur. An AUM of poor quality forage in a season of forage shortage may be worth more than an AUM of high quality forage in a season of surplus. Many other examples exist which suggest that not all AUM's are created equal and analyses assuming that they are miss the mark.

CONSIDERATION FOR MAXIMIZING LAND OUTPUT

The last point I would like to make is that there seems to be an excess of land use stereotyping. An area designated as "forestland" usually receives significant manipulation only to achieve certain levels of wood production, while "rangeland" normally receives investments designed only to improve range animal production. It seems that economists have the approaches and tools to help achieve a more efficient use of the land which could come much closer to maximizing the combined product and use values. Martin (1981) states that agricultural economists interested in rangelands would like to examine economic options for multiple product areas including the public ranges, but there is little information on the marginal rates of substitution between multiple products that may be produced on the range in addition to domestic livestock. If this is the case, perhaps range economists should play a more active role in determining what physical data should be collected (Brown 1959, Vaux 1959).

A production possibilities frontier from the Wild Bill Range in Arizona illustrates that some data are available and can be used to guide management decisions (fig. 2). A generalized curve for merchantable wood growth under uneven-aged management is illustrated here. The exact shape will vary with differences in tree size class distribution. It is assumed that a sufficiently large area is represented so that selective harvest timber sales result in removal of the equivalent of the average annual growth for the entire area each year. The forage is harvested annually across the area. Different points on the frontier are achieved by managing the timber stand at different density levels (Clary and others 1975). As the timber stand is thinned, less merchantable tree growth per acre occurs; but livestock-carrying capacity increases. Transformations of yield from one product to another is not linear, but curvilinear. The question of "what is the best combination of these two products" can be answered by applying product values.

The rental value of livestock grazing seems to be reasonably uniform among areas, while the wood values seem to be quite different depending upon the year and on wood use. In 1972 the product values were approximately \$100/MBF of ponderosa pine stumpage and \$6/AUM of grazing (Clary and others 1975). The corresponding unit values were 50 cents per cubic foot of timber and 12 cents per yearling-day of grazing. Matching the iso-revenue line to the product possibility frontier, and considering only those stands whose stem diameters are sufficient to be marketed for dimension lumber, we find that the combined product value is maximized at high tree densities where little grazing is possible (fig. 3).

The situation has changed greatly 10 years later. The rental value of grazing has maintained or even increased its value while timber stumpage values for dimension lumber have dropped considerably. Current prices for three wood products are approximately \$10 per 1,000 board feet of dimension lumber, 50 cents per cord of pulpwood, and \$7.50 per cord of fuelwood. Using these prices to construct isorevenue lines, we find that the markets available to given timber stands greatly affect the stand density at which combined grazing and timber values would be maximized. Figures 4, 5, and 6 illustrate the different results which occur depending upon the products marketed from a timber stand. If the wood is marketed for use as dimension lumber the combined value of grazing and timber is maximized at a rather low tree density where moderately high amounts of grazing and intermediate amounts of wood are produced. However, if the only market for the wood is pulp, the wood values are so low the highest combined product value is obtained by removing the timber stand and producing maximum grazing capacity. Currently, the highest wood values appear to lie in the fuelwood market. If this timber could be sold as fuelwood its higher value results in product values being maximized at intermediate timber stand densities with intermediate grazing capacities and moderately high wood growth. A dynamic programming approach (Riitters, and others 1982) used on even-aged timber management also illustrates how combined product values can maximize benefits.

The purpose here is not to belabor the wood market, but to illustrate that economic tools can and probably should be used to help guide management decisions if land management policy includes the need to maximize benefits. The same can be said for nontimber types, primarily thought of as grazing areas. In the mountain brush type, accessible from population centers, the fuelwood values of oak, maple, and similar species appear to equal or exceed grazing values even when compared on an annual production basis[1].

[1]Tiedemann, A. R.; Clary, W. P.; Wagstaff, F.; Harper, K.T. Developing management strategies for the Gambel oak habitat of the western United States. Presentation at the Annual Meeting, Utah Section, Society for Range Management, January 1981.

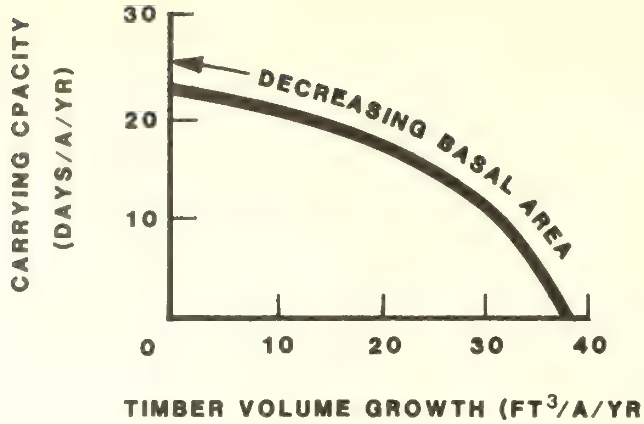

Figure 2.--Production possibilities frontier for livestock grazing and wood growth.

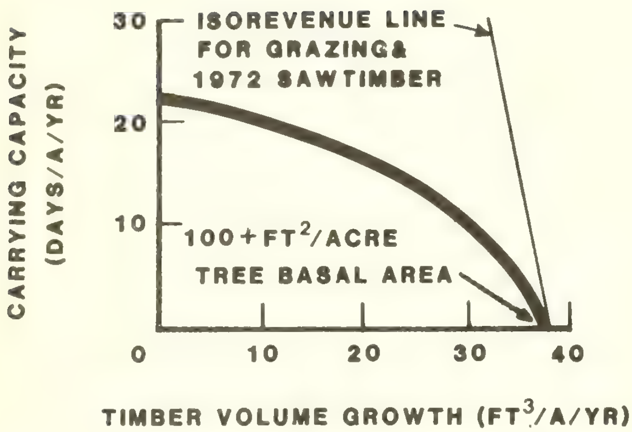

Figure 3.--Optimum thinning intensity when considering grazing and 1972 sawtimber prices.

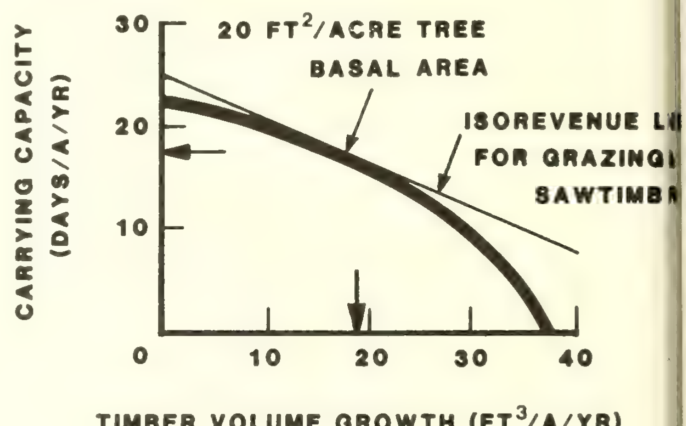

Figure 4.--Optimum thinning intensity wh considering grazing and current sawtimbe prices.

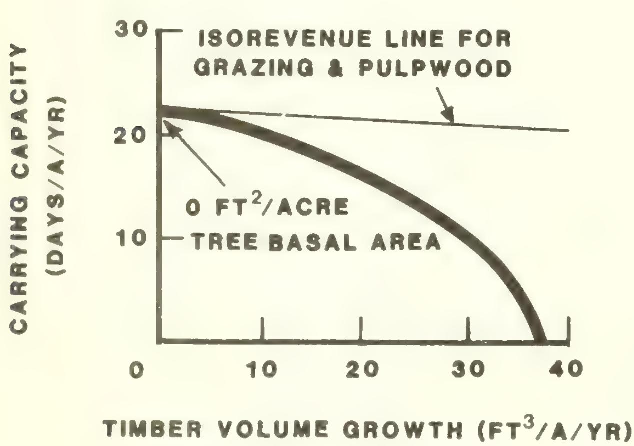

Figure 5.--Optimum thinning intensity when considering grazing and current pulpwood prices.

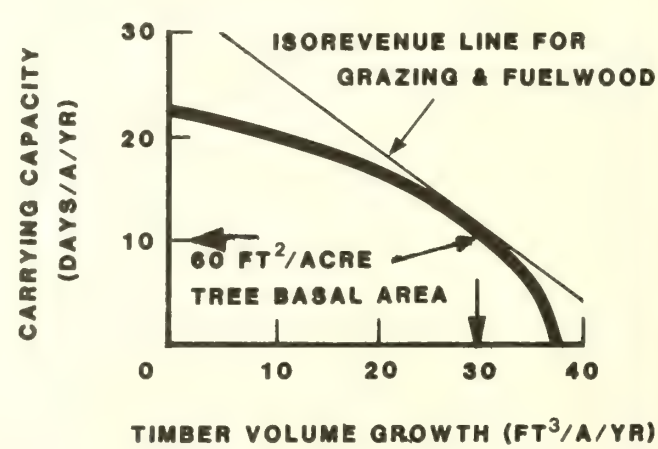

Figure 6.--Optimum thinning intensity when considering grazing and current fuelwood prices.

Liquidation of the current standing crop of Gambel oak fuelwood could result in substantial income per acre (Data on file, Shrub Sciences Laboratory, Provo, Utah). Yet, until quite recently, little thought was given to management for fuelwood production, partly due to unawareness of fuelwood values and demand, and partly due to concern about excessive sprouting of Gambel oak. Although fuelwood sales could perhaps be made without any detriment to continued grazing use of the sites, there is little documentation of the tradeoffs of increased herbaceous forage production resulting from removal of the overstory versus the potential of decreased livestock accessibility due to prolific sprout production. Additional knowledge is required for optimum management.

Many sites, however, are so thoroughly occupied by Gambel oak that there is very little long-term grazing potential. On these sites the only meaningful grazing value would occur during the early years following a fuelwood harvest. In these situations wood harvests could result in increased grazing values in addition to the potentially high fuelwood sale values. Likewise, the fuel producing potential of pinyon-juniper stands should perhaps be considered in their management. Management of an area for a single use often results in total benefits that fall far short of the potential. Use of economic tools in management decisions can improve our ability to achieve maximum benefits from the land.

CONCLUSIONS

1. Physical sampling errors and differences in site productivity can make economic analyses meaningless. If management or policy decisions are to be based on economic analysis, be sure the physical data are reliable--or don't use them.

2. Different AUM's have different values for animal production. Range economics will have more meaning if the value differences among AUM's are recognized.

3. Greater consideration should be given to maximizing combined product values. There should be increased efforts to deal with more than one use of a piece of land. Rangeland economics is more than ranch budgets.

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ECONOMETRIC ESTIMATION OF RANGE FORAGE DEMAND

Thomas M. Quigley and R. G. Taylor

ABSTRACT: Econometric analysis provides an alternative approach to the estimation of demand for forage. Econometric application requires the specification of structural forms for the production relationships, data aggregation and separation decisions, and the possible estimation of multiproduct production functions. The relationships which result may involve relatively few variables, compared to optimization studies, and data collection techniques may be simplified.

INTRODUCTION

Federal legislation and regulation have placed increased emphasis on the determination of demand and supply relationships for those goods and services being produced from Federal land. Specifically, the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976 require valuation of goods and services. Although the valuation of goods and services does not necessarily require the establishment of a price quantity relationship, Federal regulations state this as a goal (Federal Register 1979, 219.5e2, p. 53986). Federal forage is a factor (input) used principally in the production of wildlife and domestic livestock, as well as indirectly in other ecosystem outputs (for example, water, timber, and recreation). Although the theory of production includes all outputs, we will deal exclusively with domestic livestock.

Federal ownership and resulting current fee formulation circumvent competitive market pricing of forage. In the absence of markets, an indirect valuation procedure becomes necessary. A brief review of previous approaches will be presented, not to be all-inclusive but rather to outline an avenue for econometric estimation of demand.

Thomas M. Quigley is Economist at the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, La Grande, Oreg. R. G. Taylor is Research Associate of the Department of Range Science, Colorado State University, Fort Collins, Colo.

Definitions

Several distinctions are necessary to alleviate confusion and misunderstanding that might be associated with this topic. Demand in an economic sense represents the relationship between the price of a good and the quantity which consumers will purchase at the market place. Because range forage represents a factor of production (one that does not provide satisfaction in and of itself, but rather through its use in further production) its demand can be estimated through the production relationship it has with other products. In this sense, forage demand is a derived demand. Further, forage valuation represents a point estimate of demand, where any value (price) is determined for a specific quantity and time.
That field of economics which combines statistical estimation and inference with economic theory is termed econometrics. Econometrics deals primarily with stochastic problems, as opposed to deterministic techniques such as linear programing. Econometric studies of input demand have taken two main approaches. The first method relates through regression techniques, the price of the factor, and its quantity as observed in the factor market place (other variables are generally included such as the prices of substitute and complementary goods). The second method is to estimate the derived demand relationship through estimation of the production process involving the factor.

PREVIOUS WORK

The indirect approaches that have been applied to the ranching industry to determine value and/or demand of forage include: (1) comparable private lease rates, (2) alternative forage sources, (3) capitalized permit values, and (4) mathematical programing techniques. Each approach will be briefly discussed.

Comparable Private Lease Rates

The concept of a comparable private lease rate employs the idea that there exists a competitive market where forage comparable to that available on Federal land is exchanged. The lease rates observed within these markets would then represent the marginal value of the forage on private as well as comparable public land. The 1967 study by the U.S.

Departments of Interior and Agriculture used this approach to arrive at "fair market value" (Bergland and Andrus 1977). This value was estimated by reducing the comparable private lease rate, determined through survey techniques, by the unique non-fee costs associated with Federal grazing.

The obvious criticisms leveled at the comparison method are bias and error in technique such as difficulty in considering seasonal and quality variations in forage or variation in services or costs associated with the lease. The most damaging criticism of the comparison approach is not the fallibility of the technique itself but rather what the measurement represents in the absence of error. The cross-price elasticity of forage demand between private leased grazing and Federal lands has yet to be determined. When a massive amount of Federal grazing is set at a fixed price, the cross-price effect on a modicum amount of comparable private leases is unknown. Any degree of complementarity would violate the assumption of complete substitutes necessary to make a comparison valid.

Alternative Forage Sources

The approach of alternative forage sources examines the alternatives available to ranchers in acquiring forage from other sources. Hay, supplements, and pasture might be examined to determine the costs associated with acquiring this forage. Through a series of quantitative and qualitative indices the price for the alternative forage is converted into a price which is supposed to represent the value of Federal forage. This technique was applied in the 1980 RPA range valuation process and is commonly referred to as the Nebraska hay formula (United States Department of Agriculture 1980). Inconsistent results might be anticipated from this approach due to the qualitative nature in which the conversion occurs and the difficulty associated with assigning representative values to large areas of diverse vegetative composition. Again the question arises as to whether hay is a substitute or a complement in range livestock production.

Capitalized Permit Values

The theory underlying the capitalized permit value approach has been stated by Roberts (1963) and others (Gardner 1962; Roberts and Topham 1965; Roberts 1967; Martin and Jefferies 1966). The difference between grazing value and the fee plus non-fee costs are capitalized into the permit value. In addition to the inherent difficulty in estimating the value of the permit, recent questions relating to the uncertainty of permit tenure have introduced variation (Fowler and Gray 1980). Winter and Whittaker (1981) also reported that the exchange prices in land sales were not affected by permit holdings. Another criticism is that permit values like ranchlands have been subjected to speculation increases or that owning the permit has a consumptive value (that is, an intrinsic value beyond its contribution toward further production).

Mathematical Programing Approach

Optimization studies including linear programing and budget analysis constitute the majority of the technqiues applied. The current work by Gee (1981) in cooperation with the USDA Forest Service and USDI Bureau of Land Management is an example of this technique applied to the valuation of range forage. Bartlett and others (1981) utilized this approach to determine a price quantity relationship for the demand for Federal forage in Colorado. This study examined the net changes in income from beef production attributable to varying levels of Federal forage input.

Within this classification, we will include national and regional deterministic models which include livestock and/or grazing demand. These are generally optimization, such as the National Interregional Agricultural Projection (NIRAP) System (developed by the USDA Economic Research Service), or simulation (Klein and Sonntag 1982) models designed specifically for applications in planning and policy analysis. These approaches rely heavily on the alternative decision variables the analyst incorporates in the model. The price elasticities and substitution rates, important in policy analysis, associated with these models are fixed over portions of the production surface.

Substitution of inputs within a linear programing formulation occurs implicitly in alternative production activities, rather than explicitly among specific inputs. Demand estimation from linear programs relies on the analysts' formulation of alternative production activities (deterministic) rather than estimates of the degree of substitution (stochastic) which occurs within the production process.

Econometric Approach

Godfrey (1981) recently outlined research needs to estimate the demand and supply of forage. His descriptions were limited to direct econometric estimation of a demand equation using prices and the estimation of derived demand using multiple inputs and beef as a single output. We will examine the general model for multiple outputs and multiple inputs as well as discuss alternative econometric approaches which

might prove useful in forage demand estimation.

ECONOMIC THEORY OF MULTIPLE-OUTPUT PRODUCTION

Production function work prior to the 1970s, typified by Heady and Dillon's text (1961), was characterized by "engineering" type relationships. Here the design emphasized technical relationships among inputs and corresponding outputs and the determination of optimum input combinations. This contrasts with later approaches, which are designed more to relate the actual behavior of production units with the associated prices. The ultimate use of these later models is to predict how demand for inputs and supply of outputs will vary as prices change, rather than to recommend an optimal input and output mix to the producers.

The use of multiple-output functions is a necessary step for all but the simplest formulation of an estimation procedure for deriving the demand for forage. A simple cow-calf ranch operation could be modelled as a single output even though the ranch sells calves, cull cows and cull bulls. The culls can be assumed to be sold in fixed proportions to calves, thus conforming to a single output formulation. When the model incorporates cow-calf-yearling operations, the proportion of yearlings retained or purchased varies. The restriction for fixed proportions is violated and a multiple-output formulation is necessary.

Theoretical work into multiple-output production functions was pioneered by Klein (1947) in his study of the U.S. railroads. Mundlak (1963) introduced the transcendental multiple-output production function which corrected some theoretical problems associated with Klein's formulation. Work by Powell and Gruen (1968) and Mundlak and Razin (1969) has generalized the multiple-output production function to avoid possible shortcomings in formulation.

Within the ranching industry, those economic units which combine several inputs to produce several outputs constitute a ranch or firm. The general assumption is made that these firms operate so as to maximize profit. The source of revenue, outputs, as well as the source of costs, inputs, can be referred to as variables from an econometric viewpoint. The distinction between endogenous and exogenous variables is made through the interpretation of which variables are determined within the econometric model. Endogenous variables are determined within the model.

The long run situation could then be described as having all inputs and outputs endogenous. The introduction of exogenous variables render the problem to a short run situation. The prices (input and output) are placed on the firm through the market system, thus they are usually taken as exogenous. The internal technical constraint faced by the firm is provided through the multiple-output production function.

The production function faced by the firm describes the input-output combinations which are technically efficient. The technically efficient multiple-output production function can be represented by the implicit function:

$$F(Y,X) = 0 \qquad (1)$$

where Y is a vector of outputs and X is a vector of inputs. This relationship specifies those efficient combinations of inputs and outputs that are technically feasible.

Thus, given the level of all inputs and all outputs except any one, say Y_i, relationship (1) specifies the maximum amount of Y_i which can be produced. Alternatively stated, given the level of all outputs and all inputs except any one, say X_j, relationship (1) specifies the minimum amount of X_j required.

Important work into the relationship and use of profit, cost, and revenue functions in multiple-output production processes has been accomplished by Shephard (1970), McFadden (1970), Lau (1972), and Jorgenson and Lau (1974). A summary of this work together with the empirical application of several functional forms to the U.S. railroad industry is given in Hasenkamp (1976). To date, the majority of the multiple-output production studies utilizing econometrics have examined national production questions where inputs are highly aggregated.

To provide a production function which satisfies the theoretical conditions specified by multiple-output production theory, certain restrictions must be placed on the function F (Lau 1972). These include: (1) F must be continuous, twice differentiable, convex, and closed in Y and X; (2) F must be strictly decreasing in X and increasing in Y; and (3) Y must be finite for all finite X; and X must be finite for all finite Y.

Given a production function F which satisfies the above conditions, the least cost combination of inputs (X) required to produce a stated vector of outputs (Y^*) can be determined through satisfying the cost minimization problem:

$$\text{minimize} \qquad \Sigma q_i^* X_i \, ;$$

$$\text{subject to} \qquad F(Y^*,X) = 0$$

where Y^* is a given output vector and q_i^* represents the price of input X_i. This assumes that all outputs are exogenous and that the input prices are known.

The dual allows a restatement of the cost formulation above as a revenue problem. As a revenue problem, the formulation becomes the determination of the revenue maximizing combination of outputs (Y) which can be produced from a given input vector (X^*):

$$\begin{aligned} &\text{maximize} && \Sigma p_j^* \; Y_j \; ; \\ &\text{subject} && F(Y,X^*) = 0. \end{aligned}$$

When the X^* input vector is set equal to the solution of the cost problem, the resultant output vector Y from the revenue problem is the same as specified in the cost problem. This relationship is known as duality and provides a basis for much of the multiple-output econometric applications in production theory.

By combining the concepts of cost minimization with revenue maximization one arrives at the profit function. The profit function represents the solution to the problem of maximizing the difference between revenue and costs subject to the production function. Algebraically the maximization problem can be represented by:

$$B = p'Y - q'X - L(F(Y,X)) \qquad (2)$$

where p' is a row vector of output prices, q' is a row vector of input prices, and L is the Lagrangian multiplier associated with the production function constraint on profit. The maximized value of B is the profit function $B^*(p,q)$ and is given by:

$$B^*(p,q) = \max B = p'Y^* - q'X^*$$

where the * signifies the optimized values.

The derivation of the derived demand functions for the inputs comes from the familiar Shephard's Lemma (Baumol 1977). Simply stated it is that the first partial derivatives of the profit function with respect to the input price vector yield the negative of the vector of input demand functions. It further provides that the vector of output supply functions is derived from taking the first partial derivatives of the profit function with respect to the vector of output prices. Thus,

$$\partial B/\partial p = Y^*(p,q) \quad \text{and} \qquad (4)$$

$$\partial B/\partial q = X^*(p,q) \qquad (5)$$

represent the output supply and input demand functions, respectively. The properties of the profit function and the basic theorems (and proofs) regarding them are given in Lau (1972).

ECONOMETRIC APPROACHES TO FORAGE DEMAND

Now that we have outlined multiple-output production theory we can examine econometric research approaches to forage demand. These approaches can be classified into different methods; (1) direct estimation of production functions, (2) dual approach to derived demand, (3) pseudo data approach, and (4) econometric market models. Before we detail each of these approaches let us review some problems common to all approaches.

Problems Common to All Estimation Procedures

Each procedure necessarily involves decisions concerning the level at which the estimated demand will apply. These levels include firm, regional, or national. The collection of data and the applicable analysis procedure will depend on the level selected. National models may include more than one market area and, thus, price variation within a year; while firm level models may involve sampling firms which are from different market regions and estimating production relationships irrespective of region.

A related problem is which data series to employ for the estimation. The typical data sets used in econometrics are cross-sectional (one time period), time-series, and pooled. For forage demand, few consistent time-series data sets exist. This causes a particular problem for the dual estimation process which is well suited to time-series data. In fact, to avoid multicollinearity problems within the dual framework, the data must show variation in prices. This can be accomplished through time-series or multi-market data. This represents a major drawback to the estimation of input demand and output supply relationships (the dual approach) using cross-sectional data. The pseudo data approach enables the use of the dual in estimating forage demand by avoiding the multicollinearity problem through the prices selected.

Derived forage demand represents a return to what factor? Does the derived demand represent the return to beef, land appreciation, consumptive value in ranching, or some other item? This is clearer if you consider linear programing. The demand derived as in Bartlett and others (1981) is the return to beef. In formulating the multiple-output problem, the return should reflect changes in the entire production process, not just beef. This could be contrasted with the comparable private lease and capitalized permit value, which represents returns to different factors.

Regardless of the approach one takes toward the determination of Federal forage demand through econometric means, the problem of data aggregation must be addressed. The decision to aggregate should be based on theoretical, practical, and computational considerations. Heady (1961) stated that aggregation introduces bias in the estimated parameters. He suggests that quality differences exist in both inputs and outputs (every acre of land is not equal, every hour of labor is not equal) and that the failure to account for these quality differences results in specification bias. He suggests two working rules to minimize the bias due to aggregation. First, treat perfect complements, that is, resources used in fixed proportions, as a single input.` This reduces multicollinearity problems due to correlation between complements. Second, aggregate perfect substitutes into a single category. This would ideally be done using standard units; however, standardizing weights might be necessary, and these are difficult to determine in some cases.

Within the ranching industry, these problems are not trivial. For example, labor is in many forms, from hired youth to highly skilled contractors (for example, shearers), yet is often reported in total hours irrespective of the form. With respect to Federal forage demand, private forage is nearly a perfect substitute which by Heady's rule would warrant aggregation into a single input, while other seasonal forages may be perfect complements. The weighting necessary to lump irrigated pasture, alfalfa hay, supplements, and aftermath could then be approximated; and a single input reflecting forage or feed might be used. The problems are just as severe in the land and capital resources of the ranch.

Management input defies measurement, let alone a standard unit. The ranching industry is characterized by divergences in management techniques. Absentee owners, owner operators, and parttime operators have different approaches and abilities for management. In most cases, a portion of the unexplained variability can be attributed to entrepreneurial ability. Some researchers even argued that variations due to management ability are so severe that empirical production functions cannot be estimated with cross-sectional data (Walters 1963).

Another problem common to all approaches regards the statistical significance of the input of different forages. For instance, if one desires to determine the demand for Federal forage, what will happen if Federal forage is not a significant variable in the production process. This will likely be a data-related problem where significance would be found if additional and more precise data were available. The pseudo-data approach, where additional data can reasonably be obtained, may avoid this problem.

The definition of a production technology requires detailed information on quantities of inputs and outputs, additionally the dual and market approaches require prices. The lack of complete information on all inputs is specifically evident in the lack of a price for Federal forage. Obtaining physical input use is difficult and involves considerable estimation of quantities.

Another problem centers around the use of all capital assets at full capacity. Many of the survey approaches to data collection merely enumerate the items used, or owned, by the ranch. The partial use of a capital item results in a bias away from the most efficient production frontier. This introduces another variable with stochastic properties which must not be neglected.

Direct Estimation of Production Functions

The direct estimation of production functions has a long history in agriculture. Early work incorporated the popular Cobb-Douglas, Spillman, and quadratic production functions (Heady 1961), although later work introduced comprehensive functional forms such as the constant-elasticity-of-substitution (CES) and the generalized constant-ratios-of-elasticity-of-substitution-homothetic (CRESH) functions (Hanoch 1971).

The structural forms of the production relationships for ranching are not well understood. The majority of the work relating to the whole ranch production relationships has centered around linear programing formulations. Here, various alternatives are formulated and selection depends on constraints and price relationships. This represents a series of activities that are combined to form the entire ranch production process. These activity-related processes do not lead directly to the specification of multiple-output production functions. The determination of enterprise production functions may lead to simultaneous equation production relationships. A model of this type has been proposed by Johnson (1971). His model consists of the aggregation of individual "micro-functions" (which represent the basic units of farm production, breeding cow, breeding ewe, crop acre) into a whole-farm production function. The extensive data necessary to estimate the models he has proposed have prevented application.

The statistical estimation of production functions requires the level of physical inputs and outputs measured for a production process. Price information on outputs and inputs is not required during the estimation process. This contrasts with the dual

approach and represents a strength when considering non-market inputs and outputs.

The direct estimation approach has been applied with varying degees of success on agricultural operations (Walters 1963). The studies to date involving estimation of livestock production have primarily been on feedlot systems, where experimental designs have studied the feeding process. Trosper (1978) studied the ranching efficiency of Indians and whites in Montana through the use of production (and profit) function estimation. He aggregated inputs to three (land, labor, and capital) and utilized a single output (cattle sales + change in inventory + family consumption). The level of factor aggregation results in derived demand possibilities for only three inputs, thus the study did not determine the derived demand for forage.

Most empirical work with production functions has assumed a single, homogeneous output. The result of this is to derive either enterprise (corn, hay, hogs) functions or employ a common unit of measure (dollars or pounds of beef) to convert all outputs prior to derivation, such as Godfrey proposed. Using a common unit of measure restricts the output to price ratio to a constant for all outputs during the projection period.

Once a production function is specified using Federal forage as a unique input, demand can be determined. Derived demand for Federal grazing is obtained by simply finding the value of the marginal product for Federal grazing.

Dual Approach to Derived Demand

This approach involves the estimation of the parameters within the derived input demand and output supply functions (relations (4) and (5)). This implies the use of a profit function. Lau and Yotopoulos (1972) state three advantages in working with profit functions as opposed to production functions. First, it allows the derivation of output supply and input demand functions directly from an arbitrary profit function with known properties. This provides great flexibility to the researcher in that restrictions regarding substitution and output relationships are determined rather than imposed through a restrictive function. This contrasts with linear programing formulations which permit implicit substitution in inputs through alternative activities. In the direct estimation of production functions, the restrictive properties of the substitution parameters are known and specified prior to analysis of the data. Second, by starting with the profit function, it is assured through duality that the resulting system of supply and factor demand functions is obtainable from profit maximization by a firm under competition. Third, the estimated relations are functions of variables that can normally be treated as exogenous. That is, input and output prices can be taken as exogenous, and therefore estimation is less complex. By estimating these equations directly, the problem of simultaneous equation bias can be avoided. They further state that the estimation procedure should consider the supply and demand functions jointly as they will contain common parameters and restrictions should impose equality on the common factors. The estimation procedure should also consider the possibilty of errors correlated among different equations.

The major difficulty in applying this procedure to the ranching industry is data related. Necessary information for estimation includes not only the prices of outputs but also the associated prices of inputs. Thus, for each input specified, a corresponding price must be determined. For highly aggregated inputs such as capital, a weighted or average price or index corresponding to the combined inputs must be determined. As an input Federal forage must also have an associated price, which is not readily available nor without controversy.

In applying this procedure, the problem of multicollinearity becomes readily apparent. If cross sectional data were to be used, the assumption of competitive markets would necessitate estimation across several markets to provide variation in prices among inputs and outputs. This restriction results in examination of cross sectional data from a multiregional perspective. The problems become less severe when time series data are employed. The multicollinearity problem still exists and could be restrictive if prices change very little over the time series or if prices move at nearly the same rates (which might be expected from ranching data, especially for highly aggregated inputs).

This approach has been applied to agricultural data primarily at the national level. Yotopoulos and others (1976) found that the agricultural sector of Taiwan was better explained through supply and demand functions than direct production functions. Ray (1982) examined the U.S. crops and livestock industries using duality theory to explain substitutability between capital and labor. On a firm level, Trosper (1978) also used this approach to examine questions concerning efficiency of production of Indians and whites involved in ranching in Montana.

Pseudo Data Approach

The problems encountered due to lack of relevant input price data for Federal forage raise questions as to whether the duality

approach has application in determining Federal forage demand. The psuedo data approach may prove useful in assisting where data shortfalls exist. The data used in statistical estimation for this procedure are generated by an optimization model. Data point; "pseudo data," show the optimal input and output quantities corresponding to vectors of input and output prices. Through repetitive solutions to the optimization model for alternative price vectors, the shape of the production function is determined. The pseudo data representing the optimal combinations are then used to estimate the input demand and output supply functions of the profit function.

Griffen (1977, 1978) has applied this technique to the petrochemical and electrical power generation industries. He cites three principal advantages. First, the technical specification of the production surface is not limited by the historical relative price variations or environmental practices. Second, the production response surface is differentiable and can therefore be a convenient source for point elasticity estimates. Third, the cost or profit functions derived can be readily differentiated to yield estimates of input-output coefficients. The use of pseudo data techniques in the generation of input-output coefficients is demonstrated in Finan and Griffin (1978).

The pseudo data approach could prove useful in describing the production process which linear programing optimization models in ranching imply. Provided a useful production relationship could be derived, forage demand, technical efficiencies, substitutability, and elasticities could be estimated and provide better understanding into the implied relationships of the linear programing model.

Econometric Market Models

The use of econometric techniques to estimate parameters within market models is common in macroeconomic studies. Its application to natural resources has been demonstrated through the Timber Assessment Market Model (Adams and Haynes 1980). These models are characterized by simultaneous relationships representing supply and demand with the more complex models handling transactions between regions within the same solution. The Timber Model has met with much success and been held as the example to which all major resource outputs within forest planning should aim.

Essentially there have been no attempts at econometric estimation of forage market models (Godfrey 1981). The lack of an active market where AUM's of Federal forage are exchanged places a special burden on the analyst attempting market models for forage. Regional timber market models (for example, McKillop 1969) existed for some time prior to the implementation of a successful spatial market model. This appears to be a logical step for range forage modelling.

SUMMARY

The absence of a competitively determined market price for forage from Federal lands has necessitated the use of indirect techniques to estimate demand and forage value. Demand has been estimated through optimization studies utilizing mathematical programming techniques or point estimation of demand through comparable private lease rates, alternative forage sources, or capitalized permit values. These approaches are extremely sensitive to the underlying analyst's assumptions and result in considerable disagreement among studies.

Econometric analysis provides an alternative approach to demand estimation which has not been widely employed. These methods are not restricted to single output estimation and can be applied to the demand for forage at the market (regional, national, etc.) or the firm (ranch) level. The estimated elasticities and substitution rates are not necessarily predetermined by the assumptions the analyst employs.

Econometric techniques which might prove useful in the estimation of forage demand include the direct estimation of production functions, estimation of ranch output supply and input demand functions from primary data or pseudo data sources, or the estimation of market models for forage. The problems associated with the use of econometric techniques in the ranching industry are not trivial and are primarily data related.

The primary advantage to direct estimation of production functions is the lack of need for prices, while the disadvantages are the required (and restrictive) functional form and the possibility that insufficient data may result in non-significance for Federal forage as an input. Input and output prices which reflect variation are required for the dual approach, and non-significance of Federal forage is a possibility. The primary advantage of the dual is that no predetermined and restrictive form for the production function is needed. The pseudo data approach is advantageous in that the price variation is not restricted to the historical range of values. It is, however, limited in that it explains only what the generating model provides as output. Thus, the success of the pseudo approach depends on the successful modelling of the production unit initially. Econometric market models are restricted in applicability because competitive Federal forage prices are not available. Modelling the substitutes and

complements of Federal forage may be successful.

Econometric application requires the specification of structural forms for the production relationships, data aggregation and separation decisions, and the possible estimation of multi-product production functions. The relationships which result may involve relatively few exogenous and endogenous variables, compared to optimization studies, and data collection techniques may be simplified. Once the ranching industry is comprehended in this detail, forage demand may become less expensive to estimate and better understood.

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LAND USE SHIFTS IN THE GREAT PLAINS:

NEEDED INTERREGIONAL ANALYSIS OF POTENTIALS FOR

AND COMPARATIVE ADVANTAGE IN GRAZING AND CROP PRODUCTION

Giles T. Rafsnider and Melvin D. Skold*

INTRODUCTION

This paper suggests a hypothesis to explain land use shifts in the Great Plains which may accompany expanding agricultural production. Demands for private cropland, pastureland, and rangeland implicit in projected increased domestic consumption and exports contain a seeming inconsistency that may actually represent complementary production of crops and livestock. Shifts in private land use also have implications for public land management. The Intermountain Region, immediately adjacent to the Great Plains, will likely be affected by agricultural price and technology changes which alter the latter's comparative advantage in production.

The U. S. Department of Agriculture (1981, 1980) has published two analyses of present and potential productive capability of this Nation's private and public lands respectively. These studies were required by the Resources Conservation Act (PL95-192) and Resources Planning Act (PL93-378), respectively. These analyses were driven by projected increases in technology, domestic consumption, and exports. The index of agricultural productivity (1967 = 100) was projected to increase from 116 for the years 1975-77 to 147 and 187 in the years 2000 and 2030, respectively. By 2030, domestic beef and veal consumption would increase 17 percent while consumption of corn and wheat would expand 68 percent and 13 percent, respectively. For the same years, the export index was projected to increase from 169 to 290 and 351. Although not strictly comparable, an index of range grazing demand (1970 = 100) was projected to reach 185 by the year 2030.

The projections outlined above translate into a cropland production base of 457 million acres. In 1977, there were 413 million acres of cropland and 127 million acres of pastureland, rangeland, and forestland with high or medium potential for conversion to cropland. By 2030, 44 million acres will be converted to urban and other non-agricultural uses leaving 369 million acres of the present cropland base intact. Consequently, 88 million acres of privately owned pastureland, rangeland and forestland will have to be converted to cropland. Figures in Table 1 provide an idea of the domestic consumption and export increase mix which lies behind the index figures.

*Giles T. Rafsnider is Associate Professor and Melvin D. Skold is Professor, Department of Economics, Colorado State University, Fort Collins.

The shift of 88 million acres from range and pasture to cropland appears to be a substantial change. It might be asked if such a change would be seriously disruptive. Hansen's (1982) analysis of national land use patterns in Britain, Canada, and the United States sheds some light on this and related issues. He suggests that land use patterns have been shifting along a spectrum with changes in the United States not near either tail of the distribution. If this evolutionary adjustment process continues to work, future conversions are likely to be reasonably orderly.

Urbanization of 44 million cropland acres and conversion of 88 million acres from rangeland is a small production and use pattern shift in a 2 billion acre land base. However, such a shift may be unevenly distributed among subregions. In his article Hansen also noted that competition between agricultural and other uses in rural areas is stronger than that which shifts agricultural land into urban uses. Further, declines in specific agricultural uses are due as much to competition from other agricultural uses as to competition from non-agricultural rural uses.

Table 1.--Projected national increase in domestic consumption and export of selected crops and livestock in 2030 above the 1975-77 base.

Product	Projected Increases	
	Domestic Consumption	Exports
	Percent	
Beef and Veal	17	
Barley		106
Corn	68	84
Sorghum		77
Wheat	13	122

Source: United States Department of Agriculture, 1980 Appraisal, Part II, Soil, Water and Related Resources in the United States: Analysis of Resource Trends, August, 1981.

GREAT PLAINS LAND USE

Selected national projections of domestic crop and livestock consumption and export between 1977 and 2030 were summarized in Table 1. The Great Plains Region (North Dakota, South Dakota, Nebraska, Kansas, Oklahoma and Texas) has always been a

stable major supplier of these products.[1] In the 1975-1977 base period its shares of U. S. barley, corn, and sorghum production were 29 percent, 16 percent, and 86 percent, respectively. Regional shares of total winter, durham, and spring wheat production, respectively, were 47 percent, 78 percent, and 51 percent. As shown in Table 2 the regional shares of national livestock production have occurred with very little apparent aggregate land use shifts in the ten-year period as Table 3 illustrates.

To bring the impact of projected national land use changes on the Great Plains into focus, consider the following. Nationally, private pastureland, rangeland, and forestland acreages which can be cropped include 36 million acres having high and 91 million acres with medium

Table 2. --Great Plains region's shares of U. S. livestock.

Livestock Category	Regional Shares 1969	1974	1978
	--------Percent-----------		
Cattle and calves	30	30	32
Beef cows	37	33	34
Heifers	30	30	31
Steers	34	34	38
Sheep and lambs	39	38	39
Ewes	40	41	39

Source: Calculated from Censuses of Agriculture.

Table 3.--Selected great plains agricultural land use allocations measured as percentages of total land in farms in the region and nation*

	Proportions of Regional & Natl. Uses					
	1969		1974		1978	
Use Categories	GP	US	GP	US	GP	US
			Percent----	----		
Total cropland	45	16	44	16	45	16
Cropland used only for pasture or grazing	7	3	7	3	7	3
Pastureland and Rangeland	49	18	50	18	50	18

*Percentages $\frac{\text{GP Category Acreage}}{\text{GP Land in Farms Acreage}}$

$\frac{\text{GP Category Acreage}}{\text{U. S. Land in Farms Acreage}}$

Source: Calculated from Censuses of Agriculture.

[1]Usually, the eastern parts of Montana, Wyoming, Colorado, and New Mexico are also considered to be in the Great Plains. Studies cited in this paper restricted this definition to maintain state boundaries intact.

conversion potential.[2] About 70 percent will have to be converted to meet projected 2030 crop production for domestic consumption and export. Given input costs and emphasis on soil conservation, one may expect the 36 million acres having high potential will be converted first and 52 million from medium potential taken thereafter.

The National Agricultural Lands Study (1981) on competition for agricultural land reported acreages available for conversion to cropland.[3] Each of the states, except North Dakota, has over 1,000,000 acres of pasture and native pasture wit high or medium suitability for use as cropland. North Dakota contains between 500,000 and 1,000,0C acres of pasture and native pasture with high or medium suitability for use as cropland. North Dakota contains between 500,000 and 1,000,000 acre Using the lower value in these categories, conservatively at least 5.5 million acres of pasture an over six million acres of rangeland with high and medium conversion potential are found in the six Great Plains states. More recently, the ERS Grea Plains Project (1982) estimated 7,106,000 acres o pasture and rangeland with high conversion potential, and 17,582,000 acres with medium potential. The six-state total is 24,688,000 acres. If regional conversion at least mirrors national projections, 70 percent of this base will be needed. Between 8.1 and 17.3 million acres may eventually be converted to cropland. Simultaneously, USDA (1980) has projected a 61 percent increase in grazing demand for the region, suggesting direct competition between grazing and crops for land.

Substantial intra-regional use shifts have alread occurred, which cannot be detected by looking jus at regional land use figures. These shifts could lead to serious difficulties in making future adjustments. As Table 4 demonstrates, production of both cattle and grain on the same farm/ranch i a still important but decreasingly common practic Further, Table 5 indicates that by 1978 beef cattle production had been concentrated in fewer and fewer operations holding larger herds. It ma be inferred that although the land use allocation percentages do not show it, most grain and livestock production is happening on operations specializing in one or the other. It would seem at

[2]SCS/USDA, 1977 National Resource Inventory, Washington, D. C. The lands considered highly suitable require no special treatment to avoid wind and water erosion. Medium suitability indicates one or more problems may exist which require special care.

[3]The NALS reported conversion categories of 300 to 500 thousand, 500 thousand to one million, an one million acres plus.

[4]ERS/USDA, Implications of Expanded Agricultural Production for Agricultural and Natural Resource of the Great Plains, Natural Resource Economics Division Research Project Plan of Work, 1982.

first glance that further production adjustments, and particularly output expansion, must come at the expense of either crops or livestock. In a region that nearly fully utilizes its land can a 61 percent increase in grazing demand and conversion of between 8 and 17 million acres of pasture and range into cropland be accommodated simultaneously?

Table 4:--Percent of farms producing both grain and beef cattle in the Great Plains.

State	1969	1974	1978
	---------Percent------------		
North Dakota	63	53	43
South Dakota	70	55	51
Nebraska	70	54	47
Kansas	78	57	48
Oklahoma	89	42	28
Texas	20	16	4
REGION	57	42	30

Source: Calculated from Censuses of Agriculture.

Table 5:--Percent of farms holding and percent of cattle and calves held in herds of 100 or more in 1978.

State	Farms	Cattle and Calves
	------Percent -------	
North Dakota	31	67
South Dakota	41	80
Nebraska	35	82
Kansas	29	78
Oklahoma	24	70
Texas	23	77
REGION	28	77

Source: Calculated from Censuses of Agriculture

LAND USE CHANGE RECONSIDERED

At first it seems improbable that crop and livestock demands projected for the Great Plains can be met simultaneously on the region's fixed land base. But, meeting these projections may be feasible if useable aftermath accompanies crops grown on converted grazing lands. Expansion of the cropland base might not reduce feasible livestock production and could even make expanded production feasible.

Complementary crop and livestock production is possible and Table 6 indicates it already occurs in several regions of the country. It also has to be economic for producers.[5] Crops and livestock must each make positive returns before farmers and ranchers will take advantage of the complementary nature of crop aftermath in livestock production. They can also do such in several ways. Complementary production can be organized with operators producing both crops and livestock, growing crops and selling aftermath, or raising livestock and purchasing aftermath.

LAND USE FRAMEWORK

Land use conversion to crops that takes complementary forage production into consideration works along the following lines. Pasture and rangelands are converted into croplands. Crops grown may produce aftermath which offsets grazing lost. If range forage is in excess supply, while other feeds are unavailable at times in the grazing year, aftermath may solve the timing problem and could lead to expanded livestock production.

For purposes of the following discussion agricultural land is defined as cropland plus rangeland. Rangeland includes all improved and unimproved areas devoted exclusively to producing grazed forages. Two situations are analyzed. In the first case all agricultural land is utilized and production technology is constant. The second case allows technology to change. For simplicity it is assumed any acre can be used as range or cropland. Conversion costs are assumed to be constant per acre. The cropland is used to produce grain, and the rangeland grazed forages. The price received for each is independent of the other.

[5] Risk may also impose limits. Various levels and combinations of products imply capital/output and capital/labor ratios which are measures of productive efficiency and relative input use, respectively. The ratios observed along a production frontier define technical feasibility. Beyond efficiency, utilization, and technical feasibility ratios can also provide information about uncertainties. In some instances an above average or higher capital/labor ratio may indicate mechanization to avoid uncertainties in labor markets. A low ratio might imply high labor use to avoid capital costs or an aversion to debt. Limited alternate employment possibilities are also a consideration.

Table 6:--Grazing use by forage type for ranches in selected regions of the United States.

Grazing Regions	Types of Forage Grazed				
	Private Range	Rented Pasture	Grain Pasture	Crop Residue	Total
Intermountain					
Acres per ranch	1,561	620	--	186	2,397
Percent of total	65	27		8	100
Northern Great Plains					
Acres per ranch	1,141	440	--	220	1,801
Percent of total	63	24		13	100
Southern Great Plains					
Acres per ranch	1,838	958	270	81	3,147
Percent of total	58	30	8	4	100

Grazing Regions	Types of Forage Grazed				
	Pasture	Warm Grass Pasture	Cool Grass Pasture	Crop Residue	Total
Corn Belt					
Acres per ranch	210	160	215	58	648
Percent of total	32	24	33	11	100
Southeast					
Acres per ranch	203	199	98	150	650
Percent of total	31	30	15	24	100

Source: FEDS Budgets for 1977, NED/ESS/USDA, Stillwater, Oklahoma, 1981.

Constant Technology

In this hypothetical case all land is employed in the production of grain and forage. As shown in Table 7, grain yield per acre is constant while forage yields decrease in a steady "stair step" fashion. With this information it is possible to directly calculate acreage used, given production, or vice versa, for each product separately and both together. When a use shift occurs, operators will distribute land conversion in a pattern that minimizes the opportunity cost of output foregone.

The transformation relationship is shown in Figure 1. Initially product prices are such that 12 tons of grain and 22 AUM's of forage are to be produced. This is indicated by P_1 in Figure 1 which represents production frontier tangency with the inverse grain/forage price ratio. At this price ratio 12 acres are devoted to grain production and 8 acres to grazed forage production.

Now suppose an exogenous rise in grain price occurs due to increased export demand. This changes the price ratio in Figure 1 to P_2. The new level of grain production is 16 tons. The price ration change translates into 16 acres of cropland, four acres of which being converted from rangeland with a loss of 10 AUM's.

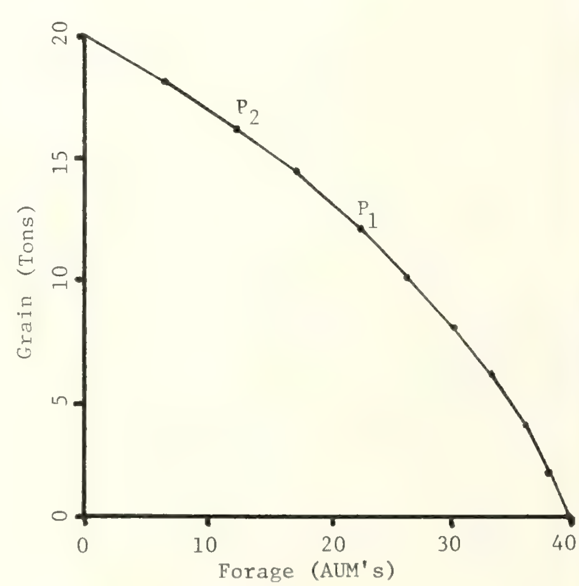

Figure 1.--Hypothetical grain/forage production possibilities

Table 7.--Hypothetical agricultural land productivity when used in grain or forage production with all land in production.

Agricultural Land					
Cropland			Rangland		
Acres	Tons	Marginal Ton/Acre	Acres	AUM's	Marginal AUM/Acre
0	0	1	0	0	3.0
2	2	1	2	6	3.0
4	4	1	4	12	2.5
6	6	1	6	17	2.5
8	8	1	8	22	2.0
10	10	1	10	26	2.0
12	12	1	12	30	1.5
14	14	1	14	33	1.5
16	16	1	16	36	1.0
18	18	1	18	38	1.0
20	20		20	40	

Agricultural land in rangeland is reduced from 8 to 4 acres and grazing from 22 to 12 AUM's. Suppose, however, a contract had been signed guaranteeing production of the original 22 AUM's. Either export income would have to be foregone or additional forage located. If grain can be planted which also yields 2.5 AUM's Acre in aftermath, lost grazing could be replaced and no income foregone.

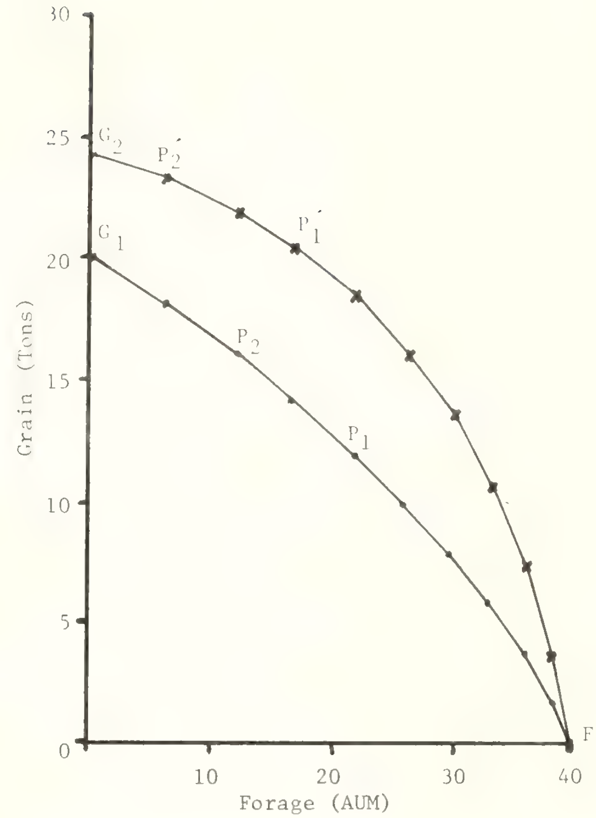

Figure 2.--Hypothetical grain/forage production possibilities following technological change in grain production.

Variable Technology

In this example technological advance is allowed. Full utilization of agricultural land continues. Both production efficiency and price increases for grain appear. Forage price and production technique remain the same. Table 8 lists the new grain production levels possible. The forage production possibilities remain as before. In Figure 2, FG_1 is the old production possibilities frontier. FG_2 is the new frontier due to technological change. The agricultural land acreage remains the same. Again, P_1 on FG_1 represents the original tangency of the price ratio inverse to the old production frontier. After increased production efficiency shifts the frontier outward and grain price increases due to additional export demand the tangency point of the new inverse price ratio is P_2' on FG_2. At this point 23.25 tons of grain are produced using 18 acres of cropland and 6 AUM's of forage on 2 acres of rangeland. Overall, land in crop production increases by six acres (from 12 to 18) while that in rangeland decreases a like amount (from 8 to 2 acres). The gain of 11.25 tons in grain requires giving up 16 AUM's of forage.

The change in production mix can be decomposed into the part due to technology change and the part due to price range. Point P_1' represents a tangency of the old inverse price ratio to the new production possibilities frontier. The vertical distance between P_1 and P_1', representing a 8.5 ton increase in grain production and two acres shifted from range to cropland, is that part of the total output mix change due to technological advance. The vertical distance between P_1' and P_2' represents an additional change of 2.75 tons of grain grown and four acres shifted from range due only to price change.

Compensating Aftermath Production

Projected increases in domestic beef, veal, and grain consumption and in grain export were mentioned earlier. Increasing grain production could prevent expanding domestic livestock output to meet projected consumption increases unless a compensating factor was at work. This factor could be grazable aftermath. The rate of per acre compensating aftermath production necessary depends on the acreage converted from rangeland to cropland as shown in Table 9. The example represents only aftermath carrying capacities required to produce 40 AUM's when

Table 8.--Hypothetical agricultural land productivity following technological change when used in grain or forage production with all land in production.

Cropland			Rangeland		
Acres	Tons	Marginal Ton/Acre	Acres	AUM's	Marginal AUM/Acre
0	0		0	0	
		2			3.0
2	4		2	6	
		2.75			3.0
4	7.5		4	12	
		1.625			2.5
6	10.75		6	17	
		1.5			2.5
8	13.75		8	22	
		1.25			2.0
10	16.25		10	26	
		1.125			2.0
12	18.5		12	30	
		1.00			1.5
14	20.5		14	33	
		.75			1.5
16	22.0		16	36	
		.625			1.0
18	23.25		18	38	
		.50			1.0
20	24.25		20	40	

Table 9.--Per acre AUM production required from aftermath to maintain forage production at the level before agricultural land was converted from range to cropland.

Acres Converted to Cropland	AUM's lost due to Conversion	Aftermath AUM's Needed Per Acre
20	40	2.00
18	34	1.88
16	28	1.75
14	23	1.64
12	18	1.50
10	14	1.40
8	10	1.25
6	7	1.16
4	4	1.00
2	2	1.00
0	0	0.00

starting with all agricultural land in range.[6] Similar tables could be constructed for other cases. Per acre production of aftermath AUM's needed depends solely on the number of acres converted to cropland and the range's carrying capacity.

Analytical Limitations

The model framework and hypothetical examples discussed are deterministic. Implementing the framework to study agricultural production and land use would require statistical treatment of both between-year and within-year variation. These variations are derived from a number of sources. First, there is year-to-year variability in range and pasture outputs and aftermath available. Range and pasture outputs depend on uncontrollable outputs like fertilizer and irrigation. Aftermath available for grazing is determined by crop production levels, harvesting techniques, and weather after harvest. The first two determine the amount of forage available. Weather after harvest determines how long the aftermath is usable. If clear weather prevails, extended grazing is possible. Heavy rain or a lengthy snow fall will make aftermath unusable. Second, there is within-year variability in forage supplies which differs for each source of grazing. Range production is inherently most uncertain due to genera weather changes and previous grazing pressure. Dryland pasture may be somewhat less variable. Irrigated pasture is relatively unaffected except for temperature shifts. Within-year aftermath variability is due to the same factors that induce uncertainty in output levels between years.

LAND MANAGEMENT PROGRAM IMPLICATIONS

The previous discussion was based on a hypothetical case. Although the values and relationships were assumed, they may reflect the relationship between livestock and crop production in the Great Plains. Livestock production in this region does not exist in a vacuum. Inevitably, changes in the Plains will be felt in other producing regions and vice-versa. This tie between regions is determined by comparative advantages based on resource endowments and location with respect to markets. In the following two subsections

[6] The figures in Table 9 are based on the hypothetical example shown in Table 8. The per acre rate would be higher when starting from a point at which both grain and forage are being produced because range forage production is variable and the example was set up with lower producing acres converted first.

implications of the model for livestock output in the Great Plains and Intermountain Regions are developed. The private and public sectors are discussed separately.

Private Sector Implications

To the extent aftermath acts as a complement in production of livestock, the competitive position of agriculture in the Great Plains and incomes of individual farmers and ranchers will be enhanced. Resources will be more fully utilized and the region's comparative and absolute advantages increased. How this increase occurs will greatly affect ranching in the Intermountain Region. Consider cattle as an example. Most Intermountain ranches are cow-calf operations heavily dependent on public grazing. This grazing supply is fixed in extent by laws, administrative regulations, and agency budgets. If cattle production in the Great Plains expands in the direction of calf production, the Intermountain Region could suffer. If, on the other hand, the expansion favors feeder or grass fat production, a larger market for calves from the Intermountain area might develop. In the extreme it could even prove worthwhile for public land based operators to develop alternative forage sources to expand their resource base and productive capacity.

The structure of Plains agriculture, as characterized by the size distribution of production units, will be important to these adjustments. Examination of the Census of Agriculture suggests 77 percent of the region's beef cattle are held in herds of 100 animals or more by only 28 percent of the farms. While crop and livestock production are carried out simultaneously on many farms the number has been falling steadily. If rangeland conversion to cropland occurs, grazable aftermath may be a complementary product. But, the extent to which conversion followed by grazing is practiced can differ among farm size classes. The likelihood and geographic pattern of this kind of resource management are unknown. The economic and sociological characteristics and their interrelationships, which can be used to predict aggregate rates and extents of adjustments made, have yet to be identified and quantified. Until that is accomplished estimates of conversion impacts and risk issues will not be as accurate as necessary for decisionmaking purposes.

Public Sector Implications

Government agencies have programs directed at private landowners and at private and public land management. How efficient these programs prove to be depends in part on landowner responses to changes in relative prices of crops and livestock and land use conversions which are part of those responses. Conversion to cropland in the Great Plains could reduce pasture and range improvement program efficiencies. When it is to the landowner's economic advantage, conversion of grazing land to cropland occurs. Public funds invested in grazing improvement may be lost. If so, return on investment, length of projects' lives, and induced impacts will decrease. Alternatively, depending on crops planted, conversion to cropland can also produce preharvest and aftermath grazing. (Winter wheat is grazed extensively in Oklahoma and Texas.) But, the level of grazing which can occur without soil degradation over time must be a consideration. This new aftermath grazing source could either provide enough fodder to maintain herd sizes or actually lead to expanded livestock numbers in the face of rangeland conversion.

A major issue for public land management is program efficiency. If the Great Plains Region's absolute and comparative advantages both increase and cow-calf production goes up, the competitive position of public land based livestock producers may erode. Range investments already completed will yield lower returns than previously projected. If programs call for investment increments being added in the future, those not already on-line will have to be reevaluated. They may be reduced or eliminated entirely. At the opposite extreme increased feeder and grass fat production in the Plains could open new markets and lead to expansion of investment programs on public lands.

The second issue is regional advantage in adopting technology. This paper deals with the Great Plains land use conversion at a regional level. The Intermountain region is more heterogeneous by comparison and will be variously impacted, accordingly. It might have fewer alternative uses for its land and even more limited supplementary or complementary production possibilities. Response to positive externalities may simply be infeasible.

At the micro level special attention will have to be paid to insure that public land management decisions are as nearly neutral as possible with respect to viability of individual ranchers. There could be situations in which decreased public activity drives ranches out of operation because the threshold between economic and non-economic sized units is narrow. Determining the effect of reduced public programs must take this narrowness into account or the real financial cost incurred will be underestimated. For example, since publicly owned resources are capitalized into the asset value of individual operations, reduced or eliminated programs can redistribute wealth away from their owners but not correspondingly increase the wealth of other individuals.

ANALYTICAL FRAMEWORK

Some major issues associated with agricultural production and land use conversion have been presented. Statistics on past and present use and projections of future production imply conflicting simultaneous demands. This conflict could be illusory. Movements between and along the extensive and intensive margins of production may resolve it.

At present, the implications drawn remain speculative. Their validity is of particular concern to the private and public sectors involved in regional livestock production and administration

of private and public domain grazing lands.[7] A research structure to provide information to deal with the issue is suggested below. It involves a sequency of three topics and associated analytical techniques.

Regionalization

The most recent USDA Appraisals were based on regions which have not been tested for statistical validity. A new regionalization of the United States is necessary which recognizes present physical, political, socioeconomic, and biological factors. Regions should be defined that are homogeneous with respect to these factors, using statistical techniques and individual time-series observations of each at the county level. The regional definition should be repeated in every census year to approximate the dynamics of national adjustments.

Production Adjustments

It was mentioned earlier that producers will expand complementary production of livestock and crops only if economic incentives to do so exist. Sufficient data are not available to determine the present extent of such production (relative to capacity) by individual operations and whether it is optimal. However, county level time-series and cross-sectional data on production, input, and land use is available at five year intervals in the Census of Agriculture. Annual compilations from the Statistical Reporting Service provide information on grain and forage crops, crops which provide aftermath grazing, and numbers of livestock by class. USDA Forest Service, ERS, and State Cooperative Extension Services provide data on production costs and associated levels of grazing. These various data can be combined to define historic production, associated costs, and land use patterns.

Several national models exist which can be used to calculate historic regional production patterns which would have been optimal in annual, five, ten year, or other intervals. Shift-share analysis will give some indication of how interested operators are in adjustments necessary to optimize income.[8]

[7]It must be briefly noted that while the problem involves western regions, it also has national ramifications. These arise from equity considerations. The western range livestock industry developed in response to social policy that promoted settlement of the nation. Title to land was granted in return for taking risks associated with settling an area which was inamicable by eastern standards. This question has and is being addressed elsewhere.

[8]Unless effects of the cattle cycle and technological change are washed out results will be indications only, not firm statements.

The data series mentioned also show the number of farms producing crops, the number of farms producing livestock, and the total number of farms in each county. When the sum of the former two exceeds the total complementary production is occurring. Statistical tests may be applied to determine if significant changes have happened across space or through time and whether there are causal relations with land use changes.

Comparative Advantage

Production functions characterize technology in place. Enterprise budgets, which are now available for most regions, represent a point on a production surface. Other points can be represented by varying the amount or the mix of inputs used in a production process. Even in the absence of functions, as several points become available, production possibility frontiers begin to be known. Alternative budgets may be estimated for subregions of the Great Plains and Intermountain Regions, or as aggregates for each using data drawn from sources listed previously. These budgets can be used to describe grain/forage production possibility frontiers and lead to better analyses of short and long-term adjustments in response to crop and livestock price shifts.

Shifts in absolute and comparative advantage, due to grazing crop aftermath, can be analyzed using these relationships. This may lead to explanation of more than just land use change. When sufficient information becomes available, marginal conditions can be derived and equated. Then, how closely efficiency is being approximated can be determined.

SUMMARY

A production and land use model and analytical approach has been suggested to evaluate what appear to be contradictory projected demands for crops and livestock. Research may reveal that implied land use conflicts actually represent complementary production of crops and livestock. If so there are major implications for public and private range and pasture management and improvement programs.

An interregional analysis is needed to determine the effects of forces, driving land use shifts, on private and public land management. The analysis involves: (1) A statistical regionalization scheme for the United States; (2) a more detailed look at production patterns over time and across space, including examination of land use patterns to identify components which affect interregional comparative advantages; (3) A production alternatives approach to estimating production possibilities frontiers and their economic implications.

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ISSUES AND PRIORITIES FOR

RANGE ECONOMICS RESEARCH

Carlton A. Infanger

ABSTRACT: Federal land policy has left a legacy of range issues that require economic analysis. The issues include: ownership, non-market outputs, ecology, management levels, distribution of benefits, and how to achieve objectivity in research. Research priorities include determining which projects will yield the greatest social returns, guiding technical research to get data useful to management, and how to allocate resources to competing uses.

INTRODUCTION

Any attempt to discuss the issues and priorities for range economics research must recognize an historical background of land settlement that was not conducive to building viable ranch units or good land stewardship. Why these conditions developed was described by Hibbard as "...a series of expedient actions put into practice from time to time...and called public policies..." (Hibbard 1965). While Hibbard may have been close, historians do not completely agree on why and/or how this nation--whose basic ideologies and institutions are rooted in private ownership--came to maintain large blocks of publicly administered lands within local government boundaries. A general consensus seems to include (1) a failure of the congress to recognize the type and size of private holdings that would be needed for economic units and (2) the development of a conservation movement as the land base was being exploited and destroyed while held as a "fugitive" resource.

Two major pieces of legislation, the Organic Administration Act of 1897 and the Taylor Grazing Act of 1934, moved federal land ownerships out of the non-mutually exclusive phases of acquisition and disposal into the equally non-exclusive reservation and management eras. Following the political and legislative struggles which led to the creation of the Bureau of Land Management in 1948, Peffer made a strong case that the public domain was "closed" (Peffer 1951). That it was closed and the new era of management was being ushered in was emphasized by the passage of the Federal Land Policy and Management Act of 1976 (FLPMA). That the issue of federal vs. state and/or private ownership was still very much alive was manifest in the "Sagebrush Rebellion" as a reaction to FLPMA.

Carlton A. Infanger is Professor of Agricultural Economics, Department of Agricultural Economics, Brigham Young University, Provo, Utah.

If management of federal lands is now enthroned, the question of managed to what ends, and for what goals, becomes paramount. The basic Forest Service guide is the famous "Pinchot Letter" signed by Secretary of Agriculture, James Wilson, on the same day that President Roosevelt signed the Transfer Act. This letter emphasized management and use and the permanence of the forest resources of wood, water, and forage. (Alston 1972) The Taylor Grazing Act gives similar direction to the management and use of BLM-administered land when, in its preamble, the objectives of stopping injury to the public lands, providing for orderly use and improvement and stabilizing the livestock industry are set forth. (Calef 1960) While these serve as general guidelines, they leave many unanswered technical questions, promote political debate, and raise questions of economic efficiency.

A review of current literature on range research gives some idea of the myriad of interrelated biological, technical, and economic questions the heterogeneous range ecology gives rise to. Moreover, those who would manage this composite range resource need the answers to these involved questions within an equally complex framework of political pressures that come from a variety of public and private interests. This diversity of interests brings forth a number of issues that need to be considered and dealt with if proposed goals are to be reached.

ISSUES

Each paper given at this conference deals with one or more issues. No doubt each participant has others that he or she might like to add. Let me suggest six broad categories that seem to consistently surface in the literature and public press: (1) ownership of range resources; (2) market vs. non-market outputs; (3) ecology and conservation; (4) levels and type of management; (5) distribution of rangeland benefits; and (6) objectivity in research.

Ownership

While I indicated in the introduction that the nation appears to be moving or has moved toward an era of management of its public rangeland, there can be little doubt that all interested parties are not satisfied with that direction. Indeed, a political compromise was needed to get the "pending final disposition" phrase in the preamble to the Taylor Grazing Act to assure its passage. (Clawson and Held 1957) The issue was raised again in 1946-48 when livestock and

conservation interests clashed over a proposal to sell all grazing lands, including those in the national forests, to the permittees. The conservation interests were so strongly represented that not a single bill proposing the transfer was introduced in Congress.

The Federal Land Policy and Management Act of 1976 has led to the current effort to get the federal land transferred to state or private interests. Less emphasis is now placed on the direct transfer to private use than was the case in the 1946-48 clash. Also, a more legalistic, rather than emotional, approach is being used. Much remains to be done to determine the economic impacts and long-run consequences if large-scale transfers by sale or grant were to occur.

Wantrup proposed that "public ownership of natural resources becomes an issue under conditions which create doubt as to the superiority of public ownership as a means to increase community welfare." He also proposed two criteria by which to measure the superiority of public ownership: "social benefit" and "conservation". (Ciriacy-Wantrup 1957) Since range resources yield several products jointly, such as water, soil protection, and recreational benefits along with livestock, society receives benefits beyond those which come from livestock products. The production of these benefits is important, but so is their distribution, which is much wider under public ownership in this nation where the tradition of free hunting and fishing is strong--a point brought against the "Sagebrush Rebellion". No doubt there are some rangelands that have little to offer in terms of outdoor recreation, and on "social-benefit" criterion, should be in private hands. Conversely, there are large blocks of land in private hands that would yield large social benefits if publicly held for critical winter game ranges--including some city lots along the Wasatch Front. Similar examples could be cited for water and/or soil protection.

Wantrup's second criterion, "conservation", indicates that public ownership is an issue when some "minimum standard of range conservation is not adopted under private ownership...through education, land-use regulations, zoning, subsidies, and other policy tools" and leaves public ownership the "safest and most economical way to guarantee a minimum standard of range conservation". High mountain watersheds and some of the "occasional acres" of the plains may be illustrative of such lands. If one assumes that the criteria of "social benefit" and "conservation" are sufficiently met to warrant public ownership for multiple use management, then consideration for both market and extra-market products needs to be accounted for.

Market vs. Non-Market

Huffman points out that there is "...great variation in the terminology used to distinguish between the benefits from resource development, which can be measured in monetary terms, and those benefits to which the dollar sign cannot be applied". (Huffman 1953) Difficulties arise with the use of "tangible" and "intangible", "markets" and "extramarket", and "market" and "non-market". The greatest problem seems to come from a philosophical "hangup" as indicated in the following statements from a recent National Research Council: (1) "There is reason to be both optimistic and cautious about the state of the art in valuation of nonmarket outputs;" and (2) "A near consensus exists in the literature that the willingness-to-pay procedure is the most appropriate conceptual framework available for valuation of nonmarket outputs." (National Research Council 1981) Both statements use the phrase "valuation of nonmarket outputs" which seems to say that that which is not in market can nevertheless be valued there. One wonders if we've forgotten the lesson of the fable of the "Midas Touch" (and I don't mean auto repairs). The idea of valuing (pricing) nonmarket goods seems somewhat incongruous; but then, don't most economists know the meaning of "valueless" while denying the existence of the "priceless". Isn't there a whole field of choices (economics) where dollar signs never come into play? The truly nonmarket goods and services such as "aesthetics, endangered species, and Indian funeral grounds" cannot be expressed in monetary terms, but does that make them any less important than those which can? (Ibid.) Many things must be included in decision making that defy being placed in monetary terms. How to do it is the problem. Perhaps what we need most is a common vocabulary that can be used by ranchers, land managers, economists, and biological scientists.

Comparisons of returns from various market products produced on rangeland can be handled within the relatively well established economic theory. To the extent that some "market valuation" of "nonmarket" goods can be made, these too can be handled. It is only with the truly "nonmarket" products that the greatest difficulty arises.

In some favorable cases, the production of market goods is complementary to nonmarket goods and vice versa; e.g., deer and cattle whose eating habits complement the production of forage prefered by the other. Also, conservation measures often produce both market and nonmarket outputs simultaneously.

Ecology and Conservation

While it may have been true a few decades ago that we didn't know enough about the range to properly manage it, more and more technical information on its ecology and conservation are becoming available. One of the major errors of the past may have stemmed from the failure to recognize that the range is a "biological resource" that exhibits some characteristics of both a flow and a fund resource: a fund of soil producing a fund of plants to produce a flow of livestock feed over time or a stock of feeds to be used up. Early users saw range forage as a fugitive resource to be captured before someone else did (both the flow and the fund aspects).

Even under private use, consciously or unconsciously, the fund aspect was, and is often depleted during drought or dismal economic times. These decreases in the fund (stock) of range plants may be accompanied by or followed by a decrease in the fund aspects of the soil itself. While levels of range productivity are increasingly man-made, decisions on how much productivity is to vary over time and around what level, need to be made. Are range users economic woes to be solved or their estates created at the expense of future productivity? A nation that worries about passing the national debt onto the next generation, when the payment will also be made to members of that next generation, should truly be alarmed at passing a depleted soil and range base onto the next generation when previous generations have used up the fund aspects.

The problems of ecology and conservation vary from range-type to range-type; e.g., plains and foothills, mountains and wilderness, prairie to desert Each type will have to be delineated if management is to be effective in the various climates and locations. Indefinite range rights, changing fees, and insecure tenure have all been very detrimental to range conservation in the past. Now we have "high" interest rates that so severely reduce the value of future benefits and returns that current exploitation is almost mandated.

Management Levels

The management of rangeland has gone, or is going, through three non-mutually exclusive types: overseeing, controlling and maximizing. As we move more into the maximizing phase, much greater attention must be paid to the premise that the "condition, or quality, of our environment may itself be considered a stock resource." (Brewer 1968) To maximize short-run outputs or profits, at the expense of the long-run aspects by using up the stock resources, may well continue the deterioration of the range resource and lead to the same type short-run situation that exists in American business where long-run capital has been depleted, or not built up, while MBA graduates have shown short-run profits for the firm.

Assuming that a management plan can avoid further disaster with respect to the fund aspect of the range, a set of workable goals for the other aspects needs to be chosen. These will have to be worked out within the political powers of the groups interested in the range output capabilities.

Alston listed the following four steps as being essential for decision makers to arrive at a correct choice among alternatives, especially in a multiple-use setting:

First.--The problem must be clearly identified and all the issues properly defined. Unless a problem is understood, it cannot be solved.

Second.--The objectives or goals that are to be served must be identified specifically. Often, these are extremely vague. Goals may be single or multiple, simple, or complex.

Third.--Once the problem and the goals to be served are clearly identified, alternative courses of action must be set forth and analyzed. Rarely is there only one way to deal with a given problem. The probable consequences of each of a number of possible alternatives must be estimated.

Fourth.--The alternatives must be appraised and the decision made. The choice of any one alternative or combination of alternatives rests on the evaluation of probable consequences. This step may, and perhaps should, include a reevaluation of the goals themselves. (Alston, Op. Cit.)

A possible fifth, implicit in Alston's third, is an assessment of resources that can be brought to bear to reach the various goals according to the weight assigned to each. This becomes particularly critical when nonmarket products are goals, but require resources with market opportunity costs to produce them. What is to be maximized becomes the crucial question. Not only what is to be maximized is important, but for what reasons and for whom it is intended.

Distribution of Range Output

Implicit in goal setting is some idea of who is to receive what, i.e., how will the output be distributed. With ownership still being an issue, albeit generally assumed to remain in federal hands, one might suppose that the returns from the range products would go to all the people of the nation. This implies that all the people, via the federal government, are the typical landlord, of the storied landlord-tenant relationship. Thus far, the history of range leasing hasn't followed the typical pattern. Adminstrative level fees have left much of the returns with the permittees. (Infanger 1964) That the value of the forage was being capitalized into commensurate property has been largely overlooked when a number of comparativ costs studies were made. Moreover, since the federal leases were not evenly distributed among ranchers, those who could not get a "low" fee federal lease maintained that they were at a disadvantage when having to pay higher private fees for grazing. The unevenness of this distribution may vary from place to place but as late as 1960 in the Northern Great Plains, 51.6 percent of the total operators got only 9.6 percent of the allowable AUM's while the largest, 9.6 percent, of the total operators got 49.7 percent. One must question that location and proximity to federal land could give such a distribution. With low fees this surely increased the rate of capital growth for the larger ranchers. Ranchers both large and small who originally received low fee permits were the recipients of a windfall of wealth creation at the expense of the nation as a whole. (Gardner 1966) Only in cases where the original owner-permittees still hold the land would an increase in fees come from those who received the

windfall. In all other cases, it would come from those who had paid the capitalized value of the low fee permits to previous owners.

As ranches have grown larger through the years by buying up smaller units, some of the disparity in range permit distribution may have been disappearing. Also, as fees increase, some of the larger permittees are suffering the largest wealth losses. Even though the among-rancher distribution may be being resolved, the problem of moving wealth out of local areas to the general treasury is being increased. So long as the local ranchers were able to keep fees low, the returns to the range remained with them and in the local economies. With fees rising, local areas are being impoverished by sending the fees to an absentee landlord (all the people via the government). One asks, "Why should the nation choose to take a capital payment from some local regions and not others?" Range fees are an insignificant part of the federal budget, but may be a large part of local income. Perhaps this is a point for state or private ownership of rangeland if no suitable way to compensate the local economies can be found with national ownership. In lieu, tax payments scarcely appear adequate.

No doubt the federal management units located in local areas do add to these areas' economies. Also, as range improvements begin, new questions of how ecological conditions can be restored and the benefits distributed among users will have to be resolved. New possibilities for greater outputs of recreation and livestock can both be generated from such improvements. Both technical and socio-economic research will be needed to give guidance to decision-makers.

Objectivity in Socio-Economic Research

The issue of objectivity is not specific to range economics research. It deserves attention here because of the multitude of groups with interests in range products. Perhaps research can never be completely devoid of value judgment, but according to Popper, "scientific objectivity consists of the freedom and responsibility of the researcher (1) to pose refutable hypotheses,(2) to test these hypotheses with relevant evidence, and (3) to state the results in an unambiguous fashion accessible to any interested person". (Castle 1968) This method is an impersonal one that permits scientists to replicate one another's work and reach the same conclusions. If it can be assumed that objectivity is in the public interest, then threats to objectivity need to be curtailed or prevented.

Castle listed five major threats that need to be guarded against: (1) the researchers desire for approval, (2) advocacy of a particular public policy, (3) vested interest in a particular theory, hypothesis, or approach, (4) desire to avoid controversial problems, and (5) desire for personal financial gain. (Ibid.) Any one of these threats may bring less than the returns society should expect of the social investment it makes in research. Moreover, those who allocate funds may bias research efforts by funding only those they expect to support their particular public policy views. This can happen in biological-technical as well as in socio-economic research.

RESEARCH PRIORITIES

Range research must compete for funds available for all research, especially for those allocated for food output enhancement in agriculture and environmental quality control. Assuming that society will continue to make a social investment in range research, what priorities can be suggested to assure that the greatest returns from the investment can be achieved? (As in the case of input-output, this becomes doubly difficult when resources that are committed have opportunity costs in the market, but the results of research may suggest greater emphasis on nonmarket products.)

Biological-Technical Data for Management Decisions

If we are correct in assuming that public ranges are to be managed for maximum returns--in whatever terms--to society, then a first priority would appear to be a determination of which types of bio-technical data would be most valuable to the managers. (Not an easy task.)

The output of research (new knowledge) is valued as an investment by society because it will enhance goal attainment. (Paulsen, Kaldor, 1968) The more important the goal, the more valuable is new knowledge to reach it. It will take the best tools that economists have, used in the most effective ways, to help guide the research investment procedure. But work with technical scientists, economists must, if limited available research resources are going to produce the greatest returns.

A group of range scientists recently identified five categories of new or unsolved problems needing research. "Ranked by priority, the five are: (1) dynamics of individual plants and plant communities; (2) identification, classification, and inventory of range ecosystems; (3) improvement of rangelands for increased productivity and stability; (4) short- and long-term grazing impacts; and (5) influence of economic, social, and political constraints on management of range resources". (Klemmedson 1978)

As an economist, one may question why economics is at the bottom of the list; yet, it is recognized that much economic analysis depends upon technical coefficients. The task is to work with the technologists early in the design stage of experiments to assure that the data generated will permit economic analysis useful to management. With research funds restricted or reduced, it becomes all the more important that those funds available be used where the greatest returns can be expected in the shortest time frame. This surely does not

mean that long-term basic research would be abandoned because some of it is mandatory to understand range dynamics, but what and how much would be based on the expected usefulness of results for decision making. This would mean that a host of projects dealing with inputs and outputs from either structural (fencing, irrigation, water development) or non-structural (revegetation, fertilization, burning, poisonous plant control, clearing, plowing, grazing intensity, etc.) improvements would be planned and carried out to yield data for management. (USDA Forest Service 1979)

Also, since rangelands produce more than forage, range research planning must include consideration for energy, recreation, minerals, wildlife, water, and how all are interrelated. Saunderson suggests that, "The watershed value of western range and forest lands often is so overwhelming as to dwarf the value of rangelands for forage yield or for short-run livestock production". (Saunderson 1975) Output competition also comes from sheep vs. cattle, livestock vs. game animals, and recreation vs. watersheds. All require physical and economic consideration. The economic framework to treat many of these problems is available when the technical coefficients can be developed.

As expressed earlier, there is a whole field of range policy research which stems from the issues of ownership, distribution of benefits, and conservation. These issues give the economic and management sciences a noble challenge to make a contribution to the maximizing of the benefits and outputs of the immense range resource. Small changes in the output of forage and/or other products per acre of range can add up to very large increases in total output over the vast western range. Efficiency of resource use requires that the effort be made to bring these increases about in cost effective ways.

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CLEARING-UP THE TECHNOLOGICAL GAP IN RANGE MANAGEMENT

John R. Lacey

ABSTRACT: Many ranchers on the Western rangelands are not using recommended range improvement practices even though results from research studies and economic analyses indicate that the improvements are profitable. This general situation is described as a technological gap. The purpose of this paper is to discuss reasons why the gap exists, and to suggest an approach that can be used to resolve the gap.

INTRODUCTION AND PURPOSE

The primary goal of this symposium was to accelerate the application of good management practices on rangelands. The importance of economics in this resource-oriented goal has been emphasized repeatedly, but now it is time to examine the human factor.

It is the range manager who makes the decisions regarding what happens on the range. The quality of his decisions depends on how well informed he was at the time the decision was made. Informed decisions require that all options and alternatives be known. The educational process necessary to implement good range management practices is referred to as technology transfer.

Educational programs in range management originated around 1950 with A.H. Walker, Ray Johnson, Karl Parker, and other early Extension Range Specialists. Their efforts followed the philosophy outlined by W.R. Chapline (Chief of Division of Range Research, U.S. Forest Service) in 1936 when he said, Extension seeks . . . . "to spread applicable knowledge of range management among the owners, users, and managers of range lands and to demonstrate and interpret desirable range-use practices adopted to local conditions in order that range lands may perform their fullest potential services, both economic and social ...." Although much progress has been made in some areas, it seems that a quality effort has not been maintained in other areas. For example, Wight (1973) and Lacey (1981) believe that many range managers do not use improvement practices even though results from research studies and economic analyses indicate that the improvements are profitable. This general situation suggests that our educational effort in the area of range economics is characterized by a technological gap. The purpose of this paper is to suggest how this technological gap in range management can be resolved. Before a solution can be proposed, it will be logical to review published data that verify the technological gap, and to discuss the factors that may be disrupting the educational flow of economic information.

RESULTS AND DISCUSSION

The Gap Exists

Biologists in the northern Great Plains have repeatedly measured biological benefits from seeding crested wheatgrass (Agropyron cristatum), Russian wildrye (Elymus junceus), and other seeded species (Lodge and others 1972; Houston and Urick 1972; Black and Reitz 1969; Smoliak 1968; and Smoliak and Slen 1974). In addition, range economists have verified the economic value of seeding these species (Godfrey and others 1979; Kearl and Cordingly 1975; Gray and Springfield 1962), and Extension Specialists (Parker 1961) have advocated their use. Although it seems that an educational package of this nature would be convincing, 70% of the ranchers in eastern Montana do not have any seeded pastures (Lacey 1981). The fact that the U.S. Forest Service has invested over 99% of all range improvement money on additional water; fences, and other structural kinds of improvements in this area (Horvath and others 1978) suggests that other range managers are also skeptical about seeding tame species. Thus, evidence suggests that range managers in the northern Great Plains are not readily adopting a recommended improvement practice.

Another example of the technological gap is the cattle breeding program in southcentral New Mexico (or lack of one), where less than 2% of the ranchers grazing Public Land have implemented a seasonal breeding program (U.S. Department of Interior 1979). This attitude certainly ignores the recommendations that are preached in beef production textbooks (O'Mary and Dyer 1978). Other examples of range managers not using recommended practices can be found throughout the western ranges. In fact, a recent report (National Cattlemen's Association 1982) found that cattlemen could effectively increase red meat production 5-20% through genetic improvement, 10-30% through a good range management program, and forage production efficiency from 20-50% by using known range improvement techniques.

John R. Lacey is the Extension Range Specialist at Montana State University, Bozeman, Mont.

A technological gap restricts production by preventing the manager from making the best possible use of the range resource. Thus, a more technically efficient operation would be able to produce more output at each level of input (figure 1). Profit is expected to increase when the new technology is adopted.

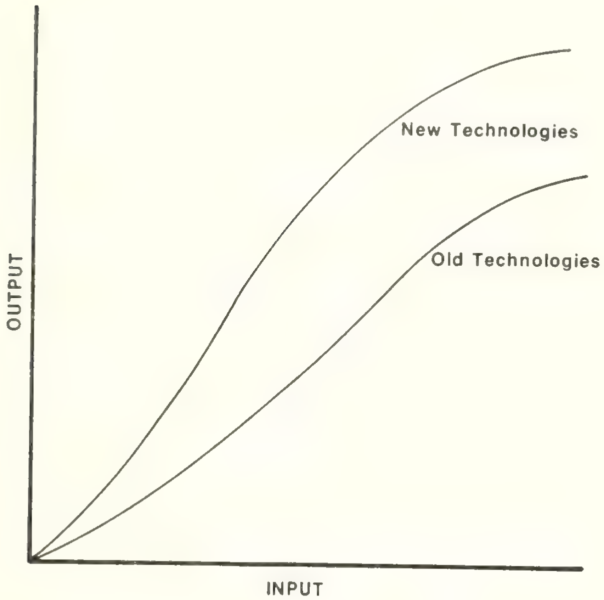

Figure 1. The level of output from a given set of input increases with new technology.

Reasons for the gap

There are at least five major explanations why land managers have not adopted recommended practices. They include: 1. faulty economic models, 2. cash flow problems on the ranch, 3. resistance to change, 4. over-optimistic research, 5. failure of the Extension Service. Because of their diversity and complexity, each will have to be discussed separately.

Faulty economic models.--James Gray pointed out in the opening session of this symposium that a tremendous resource base of range economic information has been compiled. Furthermore, this base has been significantly expanded by some of the other papers presented during this symposium. Although this logic suggests that range managers should not be suffering from the lack of technical economic information, other evidence suggests that range economics is not fully understood.

A major criticism is contained in Martin's (1972) comment regarding the Regional Research Project W-16, the "Economics of Rangeland Improvement." W-16 was activated in 1953 and aimed:

> to facilitate orderly development and conservation of the present or potential rangelands of the western region by economic evaluation of the costs and returns from range vegetation on rehabilitation and closely associated practices.

He felt that the project showed that "a lot of people put in a lot of time trying to understand the economics of range improvement investment. They were relatively unsuccessful in their efforts not because of a lack of economic sophistication, but because the response data relative to improvement practices were almost totally lacking."

It is conceivable that recommendations based on recent linear programming (LP) analyses are subjected to similar limitations. Not only do they incorporate the same biological data, but the relationships are expressed in a linear fashion. This may explain why most LP studies consistently conclude that the net income of typical ranches can be significantly increased by implementing range improvement practices and/or by switching from cow-calf to yearling operations (Lacey 1981; Hewlett and Workman 1978; Capps 1981; Leistritz and Qualey 1975). Although these conclusions may someday be verified, economists should remember that "modeling was never intended to function as a means to scientific knowledge" (Romesburg 1981). In other words, a serious credibility gap may develop if model-based recommendations are implemented by working range managers.

Cash flow problems.--Livestock producers have been and are in a period of difficult and uncertain times. This can be verified by addressing two important financial questions about a ranching operation. First, will the ranch produce sufficien net income for the ranch family to live on after all operating expenses (including loan service) hav been paid? Second, how much net ranch income (including real estate appreciation) is available to compensate investment of owned capital (equity)?

These questions can be be answered by analyzing ranch income with the modified income statement developed by Workman (1981). Fortunately, a small and large Utah cattle ranch were recently analyzed (Capps and Workman 1982) and these data should be representative of many Great Basin ranching operations.

Capps and Workman (1982) found that the small and large ranches earned a negative net return of \$14,769 and \$28,347, respectively, for family living expenses (table 1). However, after considering the mortgage principal payment and land appreciation, the ranches did receive a 3 and 2% respectively, return on owned ranch capital. This is a much lower rate than what investments in other alternatives normally receive. From a rancher's standpoint, any money for range improvements must be taken from the amount available for family living, or borrowed. Thus, it is apparent that many ranchers are caught in an economic squeeze and cannot afford to invest in any addition range improvement practices.

Table I. Modified Income Statement for Typical Composite Ranches, Utah, 1977 (Taken from Capps and Workman 1982)

ITEMS	SMALL RANCH	LARGE RANCH
Annual Cash Returns	18,361	38,944
Minus Annual Cash Cost	18,269	42,064
Minus Depreciation	4,244	10,962
Net Ranch Income	-4,152	-14,082
Minus Debt Service Cost	10,617	14,265
Net Return Available for family living expenses	-14,769	-28,347
Land appreciation	30,370	45,842
Mortgage Principal Payment	4,945	6,152
Gross Proceeds to Ranch Investment	20,546	23,647
Minus Family Labor & Management	10,000	10,000
Net Proceeds to Owned Ranch Capital	10,546	13,647
Percent Return on Owned Ranch Capital	3.13%	2.18%

Resistance to change.--A recent report by the National Cattlemen's Association (1982) found that "many cattlemen probably feel that they are operating as efficiently now as they can, but the committee's study showed that most actually are not." Furthermore, "the successful cattlemen will be innovators, willing to change and to adopt new production and marketing and business management techniques." Their optimism for change may come true because "adverse conditions are forcing more positive changes in the beef industry than all the teaching and preaching ever have" (Drover's Journal 1982).

Perhaps the cattlemen are capable of adjusting to rapid changes during the 1980's. However, Shneour (1981) reports that it often takes from 20 to 25 years before an innovative idea is readily accepted for use. His examples included the heart pacemaker which was invented in 1928 and first used in 1960, and the bicycle which was invented in 1862 and wasn't refined until 1937.

This lag period between an idea and it's adoption may have serious ramifications in our effort to implement range management practices. Range studies were not initiated until about 1900, and the Society of Range Management was not founded until 1948. Thus, range management is so new that some of the range economic principles may be ahead of their time.

Failure of the Extension Service.--Jack Artz (1982) recently discussed the progress that Extension programs in range management have made. Substantial gains were made in the areas of 1. teaching the general public about range management, 2. incorporating sound range management practices into government policy and programs, and 3. promoting programs to improve productivity and encourage sound management of private rangelands. Although this success explains why the Cooperative Extension Service (CES) is the envy of education systems worldwide, it may be possible to improve the Extension range management programs.

Some areas in which the CES could improve were discussed by Artz at a U.S./Mexico Range Management workshop (1981). He felt that we were not training people for technology transfer systems. In addition, he recognized that the Extension Service could never do the job alone, instead it should be the catalyst for technology transfer. Information must also be transferred by researchers, ranchers, and technicians. He also felt the system could be improved if information specialists and producers were full partners in policy and research planning and development.

Each of his concerns needs to be corrected within Montana's Extension Service. For example, our system does not reward researchers for their Extension work. Extension range personnel also have very little input into range research planning by the range faculty within the Animal and Range Science Department. Hopefully, many of these deficiencies will be corrected by more interaction between research and Extension personnel.

Artz's concern about Extension personnel being ill-trained in range management is substantiated in Montana, where no one can question the importance of the range resource. It covers 70% of the state, and provides most of the forage for a livestock industry, whose cash receipts total over $800 million annually. Unfortunately, only two individuals (State Extension Range Specialist and one County Agent) within Montana's Extension Service have a degree in Range Management. Instead, the agricultural county agent positions are dominated by individuals with degrees in Agricultural Education and Animal Science (table 2).

Table 2. Major areas of study by Montana County Agricultural Agents.

	Number of Individuals			
College Major	BS	Both BS & MS in field	Only MS in field (BS in other field)	Total
Agricultural Education	10	5	5*	20
Animal Science	8	8	2	18
Crops & Soils	6	1	1	8
Agricultural Econ. or Business	4	1	0	5
Misc.	0	3	0	3
	28	18	8	54

*The county agent that earned a BS degree in Range Management went on to earn a MS in Agricultural Education.

This failure to recruit range managers into the system threatens to erode the strong rapport that has been built with the producers. Producers are becoming skeptical of advisors that: 1. bring an experiment station, rather than a ranch management program to the ranch, 2. place too little value on the rancher input, and 3. do not understand the jobs or skills required in a sound ranch operation. Some producers are also losing their motivation to study range management when: 1. agencies advising them come up with several conflicting ideas, or 2. recommended improvements only assist the general environment without returning a profit to the ranch. The best way to eliminate these criticisms of the CES is to hire more personnel with range management training. Agents with this training would have the interest and knowledge to assist with range demonstration plots and would enhance inter-agency cooperation.

Over-optimistic research.--Results from some research efforts may be unintentionally inflated. This possibility exists because our American lifestyle is oriented toward success, rather than failure. Thus, in a researcher's drive to "publish or perish" he may be more inclined to undertake the tedious task of preparing an old data file containing favorable, rather than unfavorable, herbage response data for publication. He is aware that success stories from implementing range management practices are far more numerous (in our scientific and ranch magazines) than are the failures. Thus, the published range improvement information is biased-upward to the extent that our system favors success over failure.

Research is commonly conducted on small plots for economy and to decrease the possibility of environmental noise (thus increasing the possibility of uniform results). However, range managers do not have the luxury of using small plots. Instead, they must usually take the management recommendations based on small plot data, and apply it to large acreages. Any range manager who has seeded a pasture, burned sagebrush, or used a herbicide to control a noxious plant, knows that his management efforts will not result in a uniform herbage response across the treated area. Thus, from a management standpoint, the published data may be biased-upward.

Solution to the gap

It is unrealistic to single out any one of the five possible explanations as the primary culprit responsible for the gap. Instead, it is more practical to blame all five factors. This suggests that the solution is increasingly complex. However, by reviewing the various steps of the educational process, a logical solution can be derived.

Steps of the educational process.--The CES is the largest system of informed continuing education in the world. It's Extension education programs are successful because local people are directly involved in developing, executing and evaluating the programs (Hutchison 1975). However, manpower and funding make it impossible for the CES to do the job alone. Thus, the CES should be coordinating the educational effort among other agencies. This effort needs coordinating because other feder[a] agencies do employ many Range Conservationists in Montana:

Number of Range Conservationists Employed (Aug. 19[...]

Agency	Permanent
SCS	10
BLM	81
USFS	105*

*51 actually classified as Range Technicians.

Even though some of these conservationists may not have a four year degree in range, the numbers are very impressive in comparison to the number of ran[ge] trained personnel within Montana's Extension Servi[ce]

All range managers should be regarded as teachers, or conveyors of systematized knowledge. Thus, each must understand how range management information can be transferred in a form that is acceptable to the learners. This problem is compounded because there are many kinds of learners (youth, adult, private land owner, land manager, etc.), each with his own motivation, resource capability, and level of knowledge. Therefore, rather than trying to develop a single-answer approach in education programs, a specific approach is needed to address each specific situation (Ramsey and Shult 1981).

The problem of transferring range economic information can be simplified by targeting an adult audience. Adult curricula should be built around real-life problems of adults in society rather than around an academic organization of knowledge (Ramsey and Shult 1981). Therefore, education methodology of youth should not be used as a model for adult education. Adults enter into a learning experience with more and different kinds of experience than youth, and are ready for more different types of learning. These adults who are interested in further training have three major learning traits. First, they want to move ahead in meaningful areas. Second, adult learners want to build upon what they already know. Third, they have many responsibilities to work, families, and etc... Thus, adult teaching must be problem centered, the current level of student's knowledge must be known, and the learning situations must be scheduled at convenient places and times.

After a specific audience is selected, it is necessary to use the best tool to transfer the technology. Bulletins are effective if they are directed to the specific audience (Ramsey and Shult 1981). However, several studies from a wide variety of sources indicate that "the written word" may not be the best tool to implement a management practice. For example, Scandarani (1978) studied the levels of influence from different sources of information on the adoption of deferred grazing systems. Although 22 sources were available to ranchers -- personal contacts (with SCS, CES, etc) were the most important source.

"Learning by doing" or the "self-help" concept of teaching originated under the leadership of Dr. Seaman A. Knapp, U.S. Department of Agriculture educator. He established a "result demonstration" on Walter C. Porter's farm in 1903, in Texas, to show the local farmers new cropping practices designed to increase their production and eventual profits.

The farm result demonstration method was successful because it provided the means for a land holder to try new innovations with assistance of specialists in the new technology. This approach allows the landowner to do the work on his own land, and the results depend on him. In other words, as Dr. Knapp said, "what a man hears he may doubt, what a man sees he may possibly doubt, but what he does himself he cannot doubt."

Success hinges on the landholder. The specialist/educator must select a key individual in the community. One who is motivated and well perceived by his peers. A highly successful result demonstration with a rancher who has no credibility will not produce any positive spin-off.

Once a cooperator is selected, the specialist/educator should only act as an advisor. The cooperator should set objectives, make decisions, do the work, and measure results. This ensures his awareness of all contraints and problems. Thus, this situation directly contrasts with the agency-established demonstration plots that lack credibility. Agencies do not make decisions in the same context as an individual rancher.

A logical solution.--Winston Churchill's message that those who fail to study history will have to live it over is directly applicable to our problem. Obviously, more range managers must be involved with technology transfer and their tools must be developed to allow the adult to learn while doing. These are the reasons why the coordinated effort by producers, Extension, and research have been extremely successful in the Integrated Pest Management (IPM) program. Most evidence suggests that a similar program would be the best tool for addressing the technological gap in range management.

Demonstration ranches, not plots, are needed because it is necessary to analyze the entire ranching operation. For example, the dollar values of herbage increases resulting from improvement practices are much greater if they alleviate a bottleneck in the operation, rather than provide a surplus of forage during the peak of the summer growing season (Workman 1980; and Kearl 1975).

Result demonstration ranches are not a new idea. Ralphs and Busby (1978) used the approach to: 1. demonstrate and document the environmental and economic impacts of range and livestock developments on a total ranch operation, 2. involve the federal and state land management agencies with the rancher in a coordinated planning and implementation effort, 3. use the ranch as a showcase to motivate other ranchers, users, and agency administrators to support and implement range improvements, and 4. involve participation by the agricultural lenders. An added feature of this approach is the Coordinated Resource Management and Planning (CRMP) Act that dictates cooperation among the USFS, BLM, SCS, and the CES.

Funding is a serious problem for large-scale demonstration ranches. However, the 1982 Farm Bill did authorize money for a cooperative demonstration effort in range management between researchers, producers, and the Extension Service. Appropriation of funds for such an effort is the one specific goal that each of us should strive toward. This type of approach would allow herbage

response data to be quantified in economic terms. Multi-disciplinary interaction on demonstration ranches will insure that the range manager, economist, and specialist fully understand all options and alternatives. At that point, the question of the technological gap would be resolved and good range management practices implemented. Until then, this symposium cannot be termed a complete success.

CONCLUSION

This paper accomplished three things. First, it used published literature to verify the existence of a technological gap -- or an area where range economic information is not being transferred to the range manager. Second, it discussed how faulty economic models, cash flow problems, resistance to change, over-optimistic research, and failure of the Cooperative Extension Service all contribute to the gap. Third, it proposed a solution to resolve the gap.

The proposed solution hinges on an effective educational effort in range economics. While it is logical to expect the CES to take a lead role in this effort because its mission is to bring practical knowledge to the people, it is illogical to expect them to do it all. Instead, a cooperative inter-agency effort involving producers, researchers, Extension personnel, and demonstration ranches (patterned after the Integrated Pest Management Program) is the primary tool that needs to be used to facilitate this transfer of range economic information. There is no reason why range management decisions should be made without full knowledge of all available alternatives.

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ATTENDANCE ROSTER

E. T. Bartlett
Department of Range Science
Colorado State University
Fort Collins, CO 80523

Enoch Bell
Forest Resources Economics Research
Forest Service-USDA
P.O. Box 2417
Washington, DC 20013

Warren Clary
Intermountain Forest and Range Experiment Station
Shrub Sciences Laboratory
735 North 500 East
Provo, UT 84601

Richard Crom
Economic Research Service-USDA
Room 240, GHI Building
500 12th Street SW
Washington, DC 20200

William F. Davis
Intermountain Region
Forest Service-USDA
324 25th Street
Ogden, UT 84401

John M. Fowler
Department of Agricultural Economics
New Mexico State University
Box 3169
Las Cruces, NM 88003

Edward Frandsen
Range Management
Forest Service-USDA
P.O. Box 2417
Washington, DC 20013

Kerry Gee
Economic Research Service-USDA
Economics Department
Colorado State University
Fort Collins, CO 80523

E. Bruce Godfrey
Department of Economics
Utah State University
UMC-35
Logan, UT 84322

James R. Gray
Department of Agricultural Economics
New Mexico State University
Box 3169
Las Cruces, NM 88003

John Hof
Rocky Mountain Forest & Range Experiment Station
240 West Prospect
Fort Collins, CO 80526

Thad Horne
Wasatch National Forest
Forest Service-USDA
8226 Federal Building
Salt Lake City, UT 84138

Richard Howitt
Department of Agricultural Economics
University of California
Davis, CA 95616

Carlton A. Infanger
Department of Agricultural Economics
Brigham Young University
475 WIDB
Provo, UT 84602

Linda Joyce
Rocky Mountain Forest & Range Experiment Station
240 W. Prospect
Fort Collins, CO 80526

W. Gordon Kearl
Division of Agricultural Economics
University of Wyoming
Box 3354, University Station
Laramie, WY 82071

John Keith
Department of Economics
Utah State University
Logan, UT 84322

John Lacey
Range Extension
Montana State University
Bozeman, MT 59717

John McNeely
Division of Agricultural and Resource Economics
University of Nevada-Reno
Reno, NV 89557

Herb Metzger
The Flying M Land & Cattle Co.
P.O. Box 700
Flagstaff, AZ 86002

Robert Milton
Bureau of Land Management-USDI
P.O. Box 970
Moab, UT 84532

Judy Nelson
Division of Rangeland Management
Bureau of Land Management-USDI
Washington, DC 20240

Darwin B. Nielsen
Department of Economics
Utah State University
UMC-35
Logan, UT 84322

Frederick W. Obermiller
Department of Agricultural and Resource Economics
Oregon State University
Corvallis, OR 97331

Thomas M. Quigley
Pacific Northwest Forest & Range Experiment Station
Range and Wildlife Habitat Laboratory
Rt. 2, Box 2315
LaGrande, OR 97850

Tom Quinn
Malheur National Forest
Forest Service-USDA
139 NE Dayton Street
John Day, OR 97845

Teodoro Rael
New Mexico State Office
Bureau of Land Management-USDI
Santa Fe, NM 87501

Giles T. Rafsnider
Associate Professor
Department of Economics
Colorado State University
Fort Collins, CO 80525

Tom Roberts
Salt Lake District Office
Bureau of Land Management-USDI
2370 South 2300 West
Salt Lake City, UT 84119

Ervin Schuster
Intermountain Forest and Range Experiment Station
Forestry Sciences Laboratory
Drawer G
Missoula, MT 59806

Bill Swan
House Creek Ranch
Rogerson, ID 83302

John Tanaka
Department of Range Science
Utah State University
UMC-52
Logan, UT 84322

J. Kent Taylor
Fishlake National Forest
Forest Service-USDA
115 East 900 North
Richfield, UT 84701

Fred J. Wagstaff
Intermountain Forest and Range Experiment Station
Shrub Sciences Laboratory
735 North 500 East
Provo, UT 84601

William J. Weeks
Intermountain Region
Forest Service-USDA
324 25th Street
Ogden, UT 84401

Robert Williams
Targhee National Forest
Forest Service-USDA
420 North Bridge Street
St. Anthony, ID 83445

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Contains 22 papers presented at the first formal meeting of researchers and others involved in range economics since the late 1960's. Topics include the history of range economics research, critiques of recent economic evaluations, proposals of new techniques, and technology transfer.

KEYWORDS: economic evaluation, externalities, range valuation, range econometrics, range policy

55

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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C. Key to *Pseudotsuga menziesii* Habitat Types

1. *Physocarpus malvaceus* well represented . . . . . PSEUDOTSUGA MENZIESII/PHYSOCARPUS MALVACEUS h.t. (p.22)
   - 1a. *Pachistima myrsinites* usually present, sites south or east of Snake River Plains (fig. 2) . . . . . PACHISTIMA MYRSINITES phase (p.2[illegible])
   - 1b. *P. myrsinites* absent, sites north or west of Snake River Plains . . . PSEUDOTSUGA MENZIESII phase (p.23)
1. *P. malvaceus* poorly represented . . . 2

2. *Acer glabrum* or *Sorbus scopulina* well represented, sites mainly in the Snake and Bear River drainages (fig. 2) . . . PSEUDOTSUGA MENZIESII/ACER GLABRUM h.t. (p.2[illegible])
2. *A. glabrum* and *S. scopulina* poorly represented, sites not always in Snake and Bear River drainages . . . 3

3. *Vaccinium globulare* well represented . . . PSEUDOTSUGA MENZIESII/VACCINIUM GLOBULARE h.t. (p.24)
3. *V. globulare* poorly represented . . . 4

4. *Physocarpus monogynus* well represented . . . PSEUDOTSUGA MENZIESII/PHYSOCARPUS MONOGYNUS h.t. (p.[illegible])
4. *P. monogynus* poorly represented . . . 5

5. *Symphoricarpos albus* well represented . . . PSEUDOTSUGA MENZIESII/SYMPHORICARPOS ALBUS h.t. (p.[illegible])
5. *S. albus* poorly represented . . . 6

6. *Osmorhiza chilensis* or *O. depauperata* well represented . . . PSEUDOTSUGA MENZIESII/OSMORHIZA CHILENSIS h.t. (p.2[illegible])
6. *O. chilensis* and *O. depauperata* poorly represented . . . 7

7. *Spiraea betulifolia* well represented . . . PSEUDOTSUGA MENZIESII/SPIRAEA BETULIFOLIA h.t. (p.[illegible])
   - 7a. *Calamagrostis rubescens* well represented . . . CALAMAGROSTIS RUBESCENS phase (p.2[illegible])
   - 7b. *C. rubescens* poorly represented . . . SPIRAEA BETULIFOLIA phase [illegible]
7. *S. betulifolia* poorly represented . . . 8

8. *Calamagrostis rubescens* well represented . . . PSEUDOTSUGA MENZIESII/CALAMAGROSTIS RUBESCENS h.t. (p.[illegible])
   - 8a. *Pachistima myrsinites* well represented . . . PACHISTIMA MYRSINITES phase (p.2[illegible])
   - 8b. *P. myrsinites* poorly represented . . . CALAMAGROSTIS RUBESCENS phase (p.[illegible])
8. *C. rubescens* poorly represented . . . 9

9. *Cercocarpus ledifolius* well represented . . . PSEUDOTSUGA MENZIESII/CERCOCARPUS LEDIFOLIUS h.t. (p.[illegible])
9. *C. ledifolius* poorly represented . . . 10

10. *Berberis repens* or *Pachistima myrsinites* well represented, either singly or collectively . . . PSEUDOTSUGA MENZIESII/BERBERIS REPENS h.t. (p.[illegible])
    - 10a. *Carex geyeri* abundant . . . CAREX GEYERI phase* (p.[illegible])
    - 10b. *C. geyeri* not abundant; *Juniperus communis* well represented . . . JUNIPERUS COMMUNIS phase (p.[illegible])
    - 10c. Not as above, *Symphoricarpos oreophilus* abundant, stands never achieving closed canopies . . . SYMPHORICARPOS OREOPHILUS phase (p.[illegible])
    - 10d. Not as above, stands eventually achieving closed canopies . . . BERBERIS REPENS phase (p.[illegible])
10. *B. repens* and *P. myrsinites* poorly represented . . . 11

11. *Juniperus communis* well represented . . . PSEUDOTSUGA MENZIESII/JUNIPERUS COMMUNIS h.t. (p.[illegible])
11. *J. communis* poorly represented . . . 12

12. *Arnica cordifolia* well represented as the dominant forb in normally depauperate undergrowths . . . PSEUDOTSUGA MENZIESII/ARNICA CORDIFOLIA h.t. -ARNICA CORDIFOLIA phase (p.[illegible])
12. *A. cordifolia* poorly represented . . . 13

13. *Symphoricarpos oreophilus*, *Prunus virginiana*, or *Ribes cereum*, well represented . . . PSEUDOTSUGA MENZIESII/SYMPHORICARPOS OREOPHILUS h.t. (p.[illegible])
13. *S. oreophilus*, *P. virginiana*, and *R. cereum* poorly represented . . . 14

14. *Festuca idahoensis* well represented . . . PSEUDOTSUGA MENZIESII/FESTUCA IDAHOENSIS h.t.* (p.[illegible])
14. *F. idahoensis* poorly represented . . . 15

15. *Hesperochloa kingii* (*Leucopoa kingii*) common . . . PINUS FLEXILIS/HESPEROCHLOA KINGII h.t. (p.[illegible])
15. *H. kingii* scarce, *Astragalus miser* well represented or the dominant forb in normally depauperate undergrowths . . . PSEUDOTSUGA MENZIESII/ARNICA CORDIFOLIA h.t. ASTRAGALUS MISER phase (p.[illegible])

D. Key to *Picea engelmannii* Habitat Types

1. *Equisetum arvense* abundant . . . PICEA ENGELMANNII/EQUISETUM ARVENSE h.t. (p.[illegible])
1. **E. arvense not abundant . . . 2**

2. *Caltha leptosepala* common or *Trollius laxus* well represented . . . PICEA ENGELMANNII/CALTHA LEPTOSEPALA h.t. (p.[illegible])
2. *C. leptosepala* scarce and *T. laxus* poorly represented . . . 3

3. *Carex disperma* well represented . . . PICEA ENGELMANNII/CAREX DISPERMA h.t. (p.[illegible])
3. *C. disperma* poorly represented . . . 4

4. *Physocarpus malvaceus* well represented . . . PICEA ENGELMANNII/PHYSOCARPUS MALVACEUS h.t.* (p.[illegible])
4. *P. malvaceus* poorly represented . . . 5

5. *Galium triflorum*, *Actaea rubra*, or *Senecio triangularis* common, either individually or collectively . . . PICEA ENGELMANNII/GALIUM TRIFLORUM h.t. (p.[illegible])
5. Not as above . . . 6

6. *Linnaea borealis* common . . . PICEA ENGELMANNII/LINNAEA BOREALIS h.t. (p.[illegible])
6. *L. borealis* scarce . . . 7

7. *Vaccinium scoparium* well represented . . . PICEA ENGELMANNII/VACCINIUM SCOPARIUM h.t. (p.[illegible])
7. *V. scoparium* poorly represented . . . 8

8. *Juniperus communis* well represented . . . PICEA ENGELMANNII/JUNIPERUS COMMUNIS h.t. (p.[illegible])
8. *J. communis* poorly represented . . . 9

9. *Ribes montigenum* well represented or the dominant plant in normally depauperate undergrowths . . . PICEA ENGELMANNII/RIBES MONTIGENUM h.t. (p.[illegible])
9. Not as above . . . 10

10. *Arnica cordifolia* well represented . . . PICEA ENGELMANNII/ARNICA CORDIFOLIA h.t. (p.[illegible])
10. *A. cordifolia* poorly represented, *Hypnum revolutum* (a prostrate moss) well represented . . . PICEA ENGELMANNII/HYPNUM REVOLUTUM h.t. (p.[illegible])

E. Key to *Pinus albicaulis* Habitat Types

1. *Vaccinium scoparium* well represented . . . PINUS ALBICAULIS/VACCINIUM SCOPARIUM h.t. (p.[illegible])
1. **V. scoparium poorly represented . . . 2**

2. *Carex geyeri* well represented . . . PINUS ALBICAULIS/CAREX GEYERI h.t. (p.[illegible])
2. *C. geyeri* poorly represented . . . 3

3. *Juniperus communis*, *Shepherdia canadensis* or *Astragalus miser* well represented or dominant either singly or collectively . . . PINUS ALBICAULIS/JUNIPERUS COMMUNIS h.t. (p.[illegible])
   - 3a. *Shepherdia canadensis* well represented . . . SHEPHERDIA CANADENSIS phase (p.[illegible])
   - 3b. *S. canadensis* poorly represented . . . JUNIPERUS COMMUNIS phase (p.[illegible])
3. Not as above . . . 4

4. *Pinus contorta* well represented . . . PINUS ALBICAULIS/CAREX ROSSII h.t. PINUS CONTORTA phase (p.[illegible])
4. *P. contorta* poorly represented . . . 5

5. *Festuca idahoensis* common . . . PINUS ALBICAULIS/FESTUCA IDAHOENSIS h.t. (p.[illegible])
5. *F. idahoensis* scarce . . . PINUS ALBICAULIS/CAREX ROSSII h.t. -CAREX ROSSII phase (p.[illegible])

*H.t.s and phases incidental to study area and omitted from charts and tables.

APPENDIX F. EASTERN IDAHO-WESTERN WYOMING HABITAT TYPE FIELD FORM (FOR 3 PLOTS)

NAME			
DATE			
Plot No.			
Location			
T.R. S.			
Elevation			
Aspect			
Slope			
Topography			
Configuration			

(CODE DESCRIPTION)

TOPOGRAPHY:	HORIZONTAL CONFIGURATION:	CANOPY COVERAGE CLASS:	
1-Ridge	1-Convex (dry)	0=Absent	3=25 to 50
2-Upper slope	2-Straight	T=Rare to 1	4=50 to 75%
3-Mid slope	3-Concave (wet)	1=1 to 5%	5=75 to 95%
4-Lower slope	4-undulating	2=5 to 25%	6=95 to 100%
5-Bench or flat			
6-Stream bottom			

NOTE: Rate trees (>4" dbh) and regen, (0-4" dbh) separately (e.g., 4/2)

	Scientific Name	Abbrev.	Common Name	Canopy Coverage Class		
TREES						
1.	Abies lasiocarpa	ABLA	subalpine fir	/	/	/
2.	Picea engelmannii	PIEN	Engelmann spruce	/	/	/
3.	Picea glauca	PIGL	white spruce	/	/	/
4.	Picea pungens	PIPU	blue spruce	/	/	/
5.	Pinus albicaulis	PIAL	whitebark pine	/		
6.	Pinus contorta	PICO	lodgepole pine	/	/	/
7.	Pinus flexilis	PIFL	limber pine	/	/	/
8.	Pseudotsuga menziesii	PSME	Douglas-fir		/	
9.	Populus tremuloides	POTR	quaking aspen	/	/	/
SHRUBS AND SUBSHRUBS						
1.	Acer glabrum	ACGL	mountain maple			
2.	Berberis repens	BERE	creeping Oregon grape			
3.	Cercocarpus ledifolius	CELE	curlleaf mountain-mahogany			
4.	Juniperus communis	JUCO	common juniper			
5.	Ledum glandulosum	LEGL	Labrador tea			
6.	Linnaea borealis	LIBO	twinflower			
7.	Menziesia ferruginea	MEFE	menziesia			
8.	Pachistima myrsinites	PAMY	pachistima			
9.	Physocarpus malvaceus	PHMA	ninebark			
10.	Physocarpus monogynus	PHMO	mountain ninebark			
11.	Prunus virginiana	PRVI	chokecherry			
12.	Ribes cereum	RICE	squaw currant			
13.	Ribes montigenum	RIMO	mountain gooseberry			
14.	Shepherdia canadensis	SHCA	russett buffalo-berry			
15.	Sorbus scopulina	SOSC	mountain ash			
16.	Spiraea betulifolia	SPBE	white spirea			
17.	Symphoricarpos albus	SYAL	common snowberry			
18.	Symphoricarpos oreophilus	SYOR	mountain snowberry			
19.	Vaccinium caespitosum	VACA	dwarf huckleberry			
20.	Vaccinium globulare (+ membranaceum)	VAGL	blue huckleberry			
21.	Vaccinium scoparium (+ myrtillus)	VASC	grouse whortleberry			
GRAMINOIDS						
1.	Agropyron spicatum	AGSP	bluebunch wheatgrass			
2.	Calamagrostis canadensis	CACA	bluejoint			
3.	Calamagrostis rubescens	CARU	pinegrass			
4.	Carex disperma	CADI	soft-leaved sedge			
5.	Carex geyeri	CAGE	elk sedge			
6.	Carex rossii	CARO	Ross sedge			
7.	Festuca idahoensis	FEID	Idaho fescue			
8.	Hesperochloa kingii	HEKI	spike fescue			
9.	Luzula hitchcockii	LUHI	smooth woodrush			
FORBS						
1.	Actaea rubra	ACRU	baneberry			
2.	Aconitum columbianum	ACCO	monkshood			
3.	Arnica cordifolia	ARCO	heartleaf arnica			
4.	Arnica latifolia	ARLA	mountain arnica			
5.	Astragalus miser	ASMI	weedy milkvetch			
6.	Caltha leptosepala	CALE	elkslip marshmarigold			
7.	Equisetum arvensis	EQAR	common horsetail			
8.	Galium triflorum	GATR	sweetscented bedstraw			
9.	Osmorhiza chilensis (+ depauperata)	OSCH	mountain sweetroot			
10.	Pedicularis racemosa	PERA	pedicularis			
11.	Senecio triangularis	SETR	arrowleaf groundsel			
12.	Streptopus amplexifolius	STAM	twisted stalk			
13.	Thalictrum occidentale	THOC	western meadowrue			
14.	Trollius laxus	TRLA	globe flower			
15.	Xerophyllum tenax	XETE	beargrass			

SERIES			
HABITAT TYPE			
PHASE			

KEY TO SERIES, HABITAT TYPES, AND PHASES.

READ THESE INSTRUCTIONS FIRST!

1. Use this key for stands with a mature tree canopy that are not severely disturbed by grazing, logging, forest fire, etc. (If the stand is severely disturbed or in an early successional stage, the habitat type can best be determined by extrapolating from the nearest mature stand occupying a similar site.)

2. Accurately identify and record canopy coverages for all indicator species (appendix F).

3. Check plot data in the field to verify that the plot is representative of the stand as a whole. If not, take another plot.

4. Identify the correct potential climax tree species in the SERIES key. (Generally, a tree species is considered reproducing successfully if 10 or more individuals per acre occupy or will occupy the site.)

5. Within the appropriate series, key to HABITAT TYPE and PHASE by following the key literally. Verify your identification by comparing the stand conditions with the written descriptions. (The first phase in the key that fits the stand is the correct one.)

6. Use the definitions diagramed below for canopy coverage terms in the key. If you have difficulty deciding between types, refer to constancy and coverage data (appendix C-1) and the habitat type descriptions.

7. In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or duff accumulations, adjust the definitions diagramed below to the next lower coverage class (for example, well represented >1%, common >0%).

8. Remember, the key is NOT the classification! Validate the determination made using the key by checking the written description and appendix C-1.

Canopy coverage (%)	0–1	1–5	5–25	25–50	50–75	75–95	95–100
Absent	Present (not restricted to microsites)						
Scarce		Common					
Poorly represented			Well represented				
				Abundant			
Coverage class	T	1	2	3	4	5	6

KEY TO CLIMAX SERIES

(Do Not Proceed Until You Have Read The Instructions!)

1. Abies lasiocarpa present and reproducing successfully . . . . ABIES LASIOCARPA SERIES (item E)
1. A. lasiocarpa not the indicated climax 2

2. Picea engelmannii present and reproducing successfully . . . . PICEA ENGELMANNII SERIES (item D)
2. P. engelmannii not the indicated climax 3

3. Pinus flexilis a successfully reproducing dominant in old growth stands; often sharing that status with Pseudotsuga . . . . PINUS FLEXILIS SERIES (item B)
3. P. flexilis absent or clearly seral 4

4. Pseudotsuga menziesii present and reproducing successfully . . . . PSEUDOTSUGA MENZIESII SERIES (item C)
4. P. menziesii not the indicated climax dominant 5

5. Pinus albicaulis present and reproducing successfully . . . . PINUS ALBICAULIS SERIES (item F)
5. P. albicaulis not the indicated successional dominant 6

6. Pinus contorta dominant and reproducing successfully . . . . PINUS CONTORTA SERIES (item A)
6. P. contorta not the indicated successional dominant 7

7. Populus tremuloides the indicated dominant . . . . POPULUS TREMULOIDES SERIES (p.74)
7. P. tremuloides not the indicated dominant. Juniperus osteosperma or Acer grandidentatum dominating the site . . . . Minor forest types (p.75)

A. Key to Pinus contorta Community Types

1. Linnaea borealis common . . . . PINUS CONTORTA/LINNAEA BOREALIS c.t.* (p.72)
1. L. borealis scarce 2

2. Vaccinium globulare well represented . . . . PINUS CONTORTA/VACCINIUM GLOBULARE c.t.* (p.72)
2. V. globulare poorly represented 3

3. Vaccinium scoparium well represented . . . . PINUS CONTORTA/VACCINIUM SCOPARIUM c.t.* (p.72)
3. V. scoparium poorly represented 4

4. Symphoricarpos albus well represented . . . . ABIES LASIOCARPA/SYMPHORICARPOS ALBUS h.t. (p.53)
4. S. albus poorly represented 5

5. Thalictrum occidentale well represented . . . . ABIES LASIOCARPA/THALICTRUM OCCIDENTALE h.t. (p.54)
5. T. occidentale poorly represented 6

6. Osmorhiza chilensis or O. depauperata well represented either separately or collectively . . . . ABIES LASIOCARPA/OSMORHIZA CHILENSIS h.t. (p.54)
6. Not as above 7

7. Spiraea betulifolia well represented . . . . PINUS CONTORTA/SPIRAEA BETULIFOLIA c.t.* (p.72)
7. S. betulifolia poorly represented 8

8. Calamagrostis rubescens well represented . . . . PINUS CONTORTA/CALAMAGROSTIS RUBESCENS c.t.* (p.72)
8. C. rubescens poorly represented 9

9. Berberis repens common or Pachistima myrsinites well represented . . . . ABIES LASIOCARPA/BERBERIS REPENS h.t. (p.58)
9. B. repens scarce and P. myrsinites poorly represented 10

10. Carex geyeri well represented . . . . PINUS CONTORTA/CAREX GEYERI c.t.* (p.73)
10. C. geyeri poorly represented 11

11. Juniperus communis well represented . . . . PINUS CONTORTA/JUNIPERUS COMMUNIS c.t.* (p.73)
11. J. communis poorly represented 12

12. Shepherdia canadensis well represented . . . . PINUS CONTORTA/SHEPHERDIA CANADENSIS c.t.* (p.73)
12. S. canadensis poorly represented 13

13. Pedicularis racemosa common . . . . ABIES LASIOCARPA/PEDICULARIS RACEMOSA H.T. (p.60)
13. P. racemosa scarce 14

14. Arnica cordifolia or Astragalus miser well represented . . . . PINUS CONTORTA/ARNICA CORDIFOLIA c.t.* (p.73)
14. A. cordifolia and A. miser poorly represented; Carex rossii well represented or the dominant undergrowth species . . . . PINUS CONTORTA/CAREX ROSSII c.t.* (p.73)

B. Key to Pinus flexilis Habitat Types

1. Juniperus communis well represented . . . . PINUS FLEXILIS/JUNIPERUS COMMUNIS h.t. (p.19)
1. J. communis poorly represented 2

2. Cercocarpus ledifolius well represented . . . . PINUS FLEXILIS/CERCOCARPUS LEDIFOLIUS h.t. (p.19)
2. C. ledifolius poorly represented 3

3. Festuca idahoensis well represented . . . . PINUS FLEXILIS/FESTUCA IDAHOENSIS h.t. (p.20)
3. F. idahoensis poorly represented. Hesperochloa kingii (Leucopoa kingii) common . . . . PINUS FLEXILIS/HESPEROCHLOA KINGII h.t. (p.20)

*C.t.s omitted from charts and tables.

F. Key to Abies lasiocarpa habitat types

1. Equisetum arvense abundant	PICEA ENGELMANNII/EQUISETUM ARVENSE h.t. (p.36)
1. E. arvense not abundant	2
2. Caltha leptosepala common or Trollius laxus well represented	PICEA ENGELMANNII/CALTHA LEPTOSEPALA h.t. (p.37)
2. C. leptosepala scarce and T. laxus poorly represented	3
3. Carex disperma well represented	PICEA ENGELMANNII/CAREX DISPERMA h.t. (p.38)
3. C. disperma poorly represented	4
4. Calamagrostis canadensis or Ledum glandulosum well represented	ABIES LASIOCARPA/CALAMAGROSTIS CANADENSIS h.t. (p.45)
4a. Ledum glandulosum well represented	LEDUM GLANDULOSUM phase* (p.45)
4b. Not as above; Vaccinium caespitosum common	VACCINIUM CAESPITOSUM phase* (p.45)
4c. Not as above in 4a or 4b	CALAMAGROSTIS CANADENSIS phase (p.45)
4. C. canadensis and L. glandulosum poorly represented	5
5. Streptopus amplexifolius or Senecio triangularis well represented either separately or collectively	ABIES LASIOCARPA/STREPTOPUS AMPLEXIFOLIUS h. t.* (p.46)
5. Not as above	6
6. Menziesia ferruginea well represented	ABIES LASIOCARPA/MENZIESIA FERRUGINEA h.t.* (p.47)
6. M. ferruginea poorly represented	7
7. Actaea rubra common	ABIES LASIOCARPA/ACTAEA RUBRA h.t. (p.47)
7. A. rubra scarce	8
8. Physocarpus malvaceus well represented	ABIES LASIOCARPA/PHYSOCARPUS MALVACEUS h.t. (p.48)
8. P. malvaceus poorly represented	9
9. Acer glabrum or Sorbus scopulina well represented either separately or collectively	ABIES LASIOCARPA/ACER GLABRUM h.t. (p.48)
9. Not as above	10
10. Linnaea borealis common	ABIES LASIOCARPA/LINNAEA BOREALIS h.t. (p.49)
10a. Vaccinium scoparium well represented	VACCINIUM SCOPARIUM phase (p.49)
10b. V. scoparium poorly represented	LINNAEA BOREALIS phase (p.49)
10. L. borealis scarce	11
11. Xerophyllum tenax well represented	ABIES LASIOCARPA/XEROPHYLLUM TENAX h.t.* (p.50)
11. X. tenax poorly represented	12
12. Vaccinium globulare well represented	ABIES LASIOCARPA/VACCINIUM GLOBULARE h.t. (p.50)
12a. Vaccinium scoparium abundant	VACCINIUM SCOPARIUM phase (p.50)
12b. V. scoparium not abundant; Pachistima myrsinites usually present, sites mainly south or east of Snake River Plains (fig. 2)	PACHISTIMA MYRSINITES phase (p.50)
12c. P. myrsinites absent, sites mainly north or west of Snake River Plains	VACCINIUM GLOBULARE phase (p.51)
12. V. globulare poorly represented	13
13. Luzula hitchcockii common	ABIES LASIOCARPA/LUZULA HITCHCOCKII H.T.* (p.52)
13. L. hitchcockii scarce	14
14. Vaccinium scoparium well represented	ABIES LASIOCARPA/VACCINIUM SCOPARIUM h.t. (p.52)
14a. Calamagrostis rubescens well represented	CALAMAGROSTIS RUBESCENS phase (p.52)
14b. C. rubescens poorly represented; Pinus albicaulis well represented	PINUS ALBICAULIS phase (p.52)
14c. Not as above in 14a or 14b	VACCINIUM SCOPARIUM phase (p.52)
14. V. scoparium poorly represented	15
15. Arnica latifolia well represented	ABIES LASIOCARPA/ARNICA LATIFOLIA h.t. (p.53)
15. A. latifolia poorly represented	16
16. Symphoricarpos albus well represented	ABIES LASIOCARPA/SYMPHORICARPOS ALBUS h.t. (p.53)
16. S. albus poorly represented	17
17. Thalictrum occidentale well represented	ABIES LASIOCARPA/THALICTRUM OCCIDENTALE h.t. (p.54)
17. T. occidentale poorly represented	18
18. Osmorhiza chilensis or O. depauperata well represented either separately or collectively	ABIES LASIOCARPA/OSMORHIZA CHILENSIS h.t. (p.54)
18a. Pachistima myrsinites well represented	PACHISTIMA MYRSINITES phase (p.55)
18b. P. myrsinites poorly represented	OSMORHIZA CHILENSIS phase (p.55)
18. Not as above	19
19. Spiraea betulifolia well represented	ABIES LASIOCARPA/SPIRAEA BETULIFOLIA h.t. (p.56)
19. S. betulifolia poorly represented	20
20. Calamagrostis rubescens well represented	ABIES LASIOCARPA/CALAMAGROSTIS RUBESCENS h.t. (p.57)
20a. Pachistima myrsinites well represented	PACHISTIMA MYRSINITES phase (p.57)
20b. P. myrsinites poorly represented	CALAMAGROSTIS RUBESCENS phase (p.57)
20. C. rubescens poorly represented	21
21. Beberis repens common or Pachistima myrsinites well represented	ABIES LASIOCARPA/BERBERIS REPENS h.t. (p.58)
21a. Carex geyeri well represented	CAREX GEYERI phase* (p.59)
21b. C. geyeri poorly represented	BERBERIS REPENS phase (p.59)
21. B. repens scarce and P. myrsinites poorly represented	22
22. Carex geyeri well represented	ABIES LASIOCARPA/CAREX GEYERI h.t.* (p.59)
22. C. geyeri poorly represented	23
23. Juniperus communis well represented	ABIES LASIOCARPA/JUNIPERUS COMMUNIS h.t. (p.59)
23. J. communis poorly represented	24
24. Ribes montigenum well represented or the dominant plant of normally depauperate undergrowths	ABIES LASIOCARPA/RIBES MONTIGENUM h.t. (p.60)
24a. Pinus albicaulis well represented	PINUS ALBICAULIS phase (p.60)
24b. P. albicaulis poorly represented	RIBES MONTIGENUM phase (p.60)
24. Not as above	25
25. Pedicularis racemosa common	ABIES LASIOCARPA/PEDICULARIS RACEMOSA h.t. (p.60)
25. P. racemosa scarce	26
26. Arnica cordifolia, Astragalus miser, or Shepherdia canadensis well represented or the dominant undergrowth species	ABIES LASIOCARPA/ARNICA CORDIFOLIA h.t. (p.61)
26a. Picea engelmannii abundant	PICEA ENGELMANNII phase (p.62)
26b. P. engelmannii not abundant; Shepherdia canadensis well represented	SHEPHERDIA CANADENSIS phase (p.62)
26c. Not as above in 26a or 26b; Astragalus miser common	ASTRAGALUS MISER phase (p.62)
26d. Not as above in 26a, 26b or 26c	ARNICA CORDIFOLIA phase (p.65)
26. Not as above in 26; Carex rossii well represented or the dominant undergrowth species	ABIES LASIOCARPA/CAREX ROSSII h.t. (p.65)

*H.t.s and phases incidental to study area and omitted from charts and tables.

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APPENDIX C-2. PRESENCE LIST: NUMBERS OF SAMPLE STANDS WHERE EACH SPECIES OCCURRED, BY HABITAT TYPE AND PHASE (con.)

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PINUS FLEXILIS HEKI n=22	FEID n= 3	CELE n= 3	JUCO n= 6	STOR n=15	ABCO ABCO n=21	ABCO AGMI n= 3	CELE n= 8	JUCO n=21	BERE STOR n= 3	BERE JUCO n= 6	BERE BERE n=24	CARU PAMY n=13	CARU CARU n=27	SPBE CARO n=10	SPBE SPBE n= 9
	PERENNIAL FORBS																
436	Campanula rotundifolia	12	2	0	2	1	5	1	1	6	0	2	0	0	1	1	2
860	Castilleja chromosa	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
866	Castilleja flava	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
807	Castilleja gracillima	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
824	Castilleja linariaefolia	1	0	1	0	0	2	1	1	1	0	1	0	0	0	0	0
438	Castilleja miniata	0	0	0	1	0	0	0	0	1	0	0	3	2	1	1	0
594	Castilleja rhexifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
440	Cerastium arvense	2	0	0	2	0	1	0	0	1	0	0	0	0	0	0	0
442	Chimaphila umbellata	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0
444	Claytonia lanceolata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
599	Clematis pseudoalpina	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
448	Comandra umbellata	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
450	Corallorhiza maculata	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0
451	Corallorhiza striata	0	0	0	0	0	0	0	1	0	0	0	1	1	1	2	0
602	Crepis acuminata	13	3	1	0	2	1	1	4	4	1	2	2	1	4	0	2

APPENDIX C-2. PRESENCE LIST: NUMBERS OF SAMPLE STANDS WHERE EACH SPECIES OCCURRED, BY HABITAT TYPE AND PHASE

ADP NO.	SERIES / HABITAT TYPE / PHASE / NUMBER OF STANDS	PINUS FLEXILIS HERI n=22	PINUS FLEXILIS FEID n= 3	PINUS FLEXILIS CELE n= 3	PINUS FLEXILIS JUCO n= 6	PSEUDOTSUGA MENZIESII SYOR n=15	ARCO ARCO n=21	ARCO ASMI n= 3	CELE n= 8	JUCO n=21	BERE SYOR n= 3	BERE JUCO n= 8	BERE BERE n=24	CARU FAMT n=11	CARU CARU n=37	SPBE CARU n=10	SPBE SPBE n= 9
	TREES																
002	Abies lasiocarpa	0	0	0	0	0	0	0	0	2	0	0	2	3	1	0	0
004	Juniperus scopulorum	4	0	0	1	5	2	1	6	5	1	0	5	1	1	0	2
007	Picea engelmannii	1	0	0	0	0	2	0	0	4	0	0	0	0	0	0	0
008	Picea glauca	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
022	Picea pungens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
009	Pinus albicaulis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
010	Pinus contorta	2	0	0	3	0	3	1	0	3	0	4	2	2	11	3	2
011	Pinus flexilis	22	3	3	6	7	10	3	2	16	1	2	4	1	2	1	3
014	Populus tremuloides	3	0	0	1	3	2	1	0	3	0	2	3	5	1	2	0
016	Pseudotsuga menziesii	18	1	3	1	14	21	3	8	21	3	4	23	13	26	10	9
	SHRUBS																
102	Acer glabrum	0	0	0	0	4	4	1	1	1	0	2	12	7	2	4	4
167	Acer grandidentatum	0	0	0	0	0	0	0	1	0	0	0	4	0	1	1	0
105	Amelanchier alnifolia	0	0	2	0	3	2	0	4	3	3	2	20	11	9	4	4
150	Artemisia tridentata	11	3	3	1	3	3	1	5	3	2	0	1	1	6	1	0
107	Ceanothus velutinus	0	0	2	0	0	0	0	1	0	0	0	2	2	0	1	0
173	Cercocarpus ledifolius	0	0	3	0	0	0	0	8	0	1	0	3	0	1	0	0
152	Chrysothamnus viscidiflorus	0	0	3	0	1	0	0	3	0	0	0	0	0	0	0	0
109	Cornus stolonifera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0